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TRENTON, NEW JERSEY 08628

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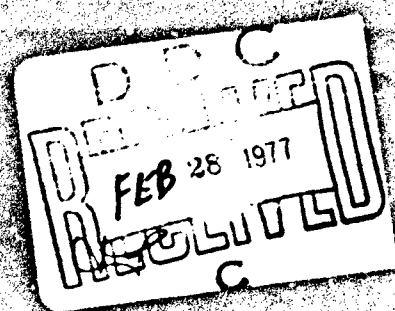
JANUARY 1977

ANALYSIS AND TESTING OF JP-5 FUEL DERIVED FROM COAL

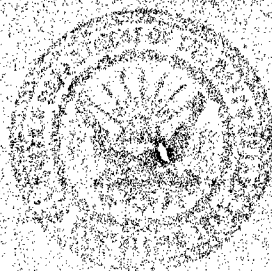
By: C. J. Nowack

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20 ABSTRACT (Continue on reverse side if necessary and identify by block number) Syncrudes derived from Utan and Western Kentucky coals by the COED process were refined into 10 gallon quantities of a JP-5 type aviation fuel. The kerosene cuts from the two syncrudes were hydrotreated in two stages. A single stage treatment provided a high aromatic (20-25 percent volume) fuel and the two stages a low aromatic (0-5 percent) fuel. The properties of the four synfuels were evaluated for their conformance to the MIL-T-5624K specification requirements for grade JP-5. Material compatibility and		

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NAVAL AIR PROPULSION TEST CENTER

TRENTON, NEW JERSEY 08628

PROPULSION TECHNOLOGY AND PROJECT ENGINEERING DEPARTMENT

NAPTC-PE-99

JANUARY 1977

ANALYSIS AND TESTING OF JP-5 FUEL DERIVED FROM COAL

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CONVERSION FACTORS: SI TO U.S. CUSTOMARY UNITS

<u>Convert From</u>	<u>To</u>	<u>Multiply by</u>
degree Celsius ($^{\circ}\text{C}$)	degree Fahrenheit ($^{\circ}\text{F}$)	$t_{\text{F}} = 1.8 t_{\text{C}} + 32$
joule per kilogram (J/kg)	British thermal unit per pound (BTU/lb)	$4.299\ 226 \times 10^{-4}$
kilogram (kg)	pound (lb)	2.204 622
kilogram per second (kg/s)	pound per hour (lb/hr)	$7.936\ 640 \times 10^3$
kilogram per watt per second (kg/W·s)	pound per horsepower per hour (lb/HP·hr)	$5.918\ 352 \times 10^6$
litre per second (l/s)	gallon per minute (gpm)	$1.585\ 030 \times 10^1$
metre (m)	inch (in)	$3.937\ 007 \times 10^1$
metre ² (m ²)	inch ² (in ²)	$1.550\ 003 \times 10^3$
metre ³ (m ³)	gallon (gal)	$2.641\ 720 \times 10^2$
metre ² per second (m ² /s)	centistokes (cSt)	$1.000\ 000 \times 10^6$
newton (N)	pound-force (lb-force)	$2.248\ 089 \times 10^{-1}$
pascal (Pa)	pound per square inch (psi)	$1.450\ 377 \times 10^{-4}$
watt (W)	horsepower (HP)	$1.341\ 022 \times 10^{-3}$

INTRODUCTION

The Naval Air Propulsion Test Center (NAPTC) is investigating alternate sources (coal, shale and tar sands) that could be used to produce JP-5. This work is being conducted under Work Unit Plan No. 812 which is authorized by reference 1. This report covers the phase of the work that was performed on JP-5 type fuels derived from coal.

Since no JP-5 type fuel derived from coal was available, a contract was awarded to the Sun Oil Company (reference 2) to refine synthetic crude oils (syncrudes) derived from coal into JP-5 type fuels. The coal syncrudes were furnished to NAPTC by the U.S. Energy Research and Development Administration in response to reference 3. Fifty-four barrels (8.58 metres³ (2268 gallons)) of syncrudes derived from Western Kentucky and Utah coals were furnished. The coals had been converted to the liquid state by the Char Oil Energy Development (COED) process (reference 4) by the EOC Corporation of Princeton, New Jersey.

The Sun Oil contract consisted of two phases. Phase I required the refining of each syncrude into JP-5 type fuels having low (0-5 percent) and high (20-25 percent) aromatics content in 0.04 m³ (10 gallons) quantities. Phase II required the refining of 0.95 m³ (250 gallons) of a high aromatic content JP-5 type fuel from the syncrude derived from Western Kentucky coal. The selection of the aromatic content and syncrude source was based upon the analysis of the Phase I samples.

The testing of the Phase I samples consisted of analysis, accelerated storage stability, and compatibility with elastomeric materials and copper. This work was performed under the reference 1 authorization. The larger quantity of the Phase II sample permitted larger scale/component testing to supplement the laboratory type testing performed on the equivalent Phase I sample. The actual tests performed on the Phase II sample were analysis, T63-A-5A engine performance and exhaust emissions tests and filter/separator coalescer tests. The Phase II work was authorized by reference 5. Although the Phase I and Phase II testing were supported by different Naval Air Systems Command (NAVAIR) groups (AIR-330 and AIR-536, respectively), it was considered advisable to combine the results into this one report to provide a complete package of related information.

In this report, the primary information is contained in the Appendices, each of which covers a specific area of the investigation. Each Appendix is a report in itself and the information they contain is summarized in the body of this report.

CONCLUSIONS

1. Fuel can be refined from synthetic crudes derived from coal, utilizing a high degree of hydrogenation, to meet all the requirements of JP-5 but for the gravity/density of the fuel. The optimum JP-5 type fuel refined from coal had a specific gravity value that exceeded the JP-5 maximum limit by 12 percent. The gravity/density problem is inherent to the chemical composition of coal fluids and is not a disqualifying factor as far as aircraft engine operation is concerned.

2. The JP-5 type fuels derived from coal exhibit similar material compatibilities and additive response to that of JP-5 derived from petroleum except that they have a greater capability to dissolve water. When fuels derived from coal and petroleum are mixed together, there is evidence that a detrimental effect on coalescer performance results.
3. The variation in freeze point of fuels derived from coal is related to the source of the coal, is not greatly affected by the degree of hydrogenation of the synthetic crude but is affected by distillation range of the resulting fuel.
4. Engine performance and exhaust emissions for the JP-5 type fuel derived from coal were equivalent to those obtained with petroleum derived JP-5 during short tests in a T63-A-5M engine.

RECOMMENDATIONS

1. Syncrudes representing additional sources of coal and processes to derive syncrudes should be subjected to similar investigations.
2. The water solubility characteristics of JP-5 type fuels derived from coal should be subjected to more detailed investigation as well as the effect of blends of coal and petroleum derived fuels on filter/separator coalescer performance.
3. More extensive engine/combustor testing of fuels derived from coal should be performed to determine the existence of any hot section component problems.

DESCRIPTION

1. All of the tests and procedures used to investigate the characteristics and performance of the fuels derived from coal are completely described in Appendices A through G. These are all tests that have been and are used in industry and by this Center to investigate fuel characteristics and performance.

DISCUSSION AND ANALYSIS OF RESULTS

1. Analysis of Phase I Coal Derived JP-5 Type Fuels

a. The characteristics of the fuels with high aromatic content (single stage hydrogenation) tended to be marginal or deficient, when compared to JP-5, in viscosity, gravity, freeze point, smoke point and thermal stability. Reducing the aromatic content of these fuels to a minimum level of 0-5 percent (two stage hydrogenation) corrected the smoke point and thermal stability problems. The viscosity problem was correctable by reducing the initial and end point distillation temperatures of the fuel which in turn is detrimental to the yield of the fuel (from the crude). The freeze point was affected primarily by the source of the coal rather than the aromatic content/degree of hydrogenation. The fuels derived from the Western Kentucky coal had very good freeze points whereas the fuels derived from the Utah coal were significantly higher. The gravity values also improved with the decrease in

distillation end point temperature but not to the range required for JP-5. The gravity problem is related to the decalin type compounds which are the major compounds found in these fuels. These compounds basically have higher gravity values than the compounds found in petroleum derived fuels. Therefore this is the one property of coal derived fuels that is for practical purposes impossible to adjust to meet the JP-5 requirement; however, the gravity value of the fuel is not critical to the operation of gas turbine engines.

b. The coal derived fuel contained more dissolved water than did normal JP-5. However, the coal derived fuel did respond to the addition of the fuel system icing inhibitor (FSII) to the same degree as did normal JP-5.

c. Further details on the various tests conducted may be found in Appendix A.

2. Storage Stability of Phase I Coal Derived Fuels

a. The four fuels were subjected to 26 weeks storage at 43°C (110°F). Based on tests conducted before and after the storage period, there was no degradation of the thermal oxidation stability characteristics. The gum content of one of the samples increased significantly; however the use of an oxidation inhibitor eliminated this increase in gum content. These fuels are compatible with oxidation inhibitors and it may be necessary to mandate their use with these fuels.

b. Further details on the various tests conducted may be found in Appendix B.

3. Compatibility of Phase I Coal Derived Fuels with Copper

a. Exposing the coal derived fuels and JP-5 to copper resulted in solubilization of copper in all the fuels. The high aromatic content fuels had the greatest rate of copper solubilization whereas the low aromatic content fuels had the least rate. All the fuels suffered significant deterioration in their thermal oxidation stability characteristics when they contained 200 ppb of dissolved copper.

b. Further details on the tests conducted may be found in Appendix C.

4. Compatibility of Phases I and II Coal Derived Fuels with Elastomers

a. These fuels and a JP-5 were subjected to 28 day storage tests at a temperature of 52°C (120°F) with each of the elastomeric materials that fuel contacts in the S3A aircraft. At the end of the test, no adverse effects on any of the elastomeric materials were noted.

b. Further details on the tests conducted may be found in Appendix D.

5. Analysis of JP-5 Type Fuel (Phase II) Derived From Coal

a. Based on Recommendations contained in paragraphs 3.a. and 3.b. of Appendix A, the 0.95 m³ (250 gallons) of JP-5 type fuel for component testing were refined from Western Kentucky coal. The fuel was refined to contain a high aromatic content (20-25 percent) and lower initial and end point distillation temperatures than the equivalent Phase I fuel. The lower distillation temperatures were new requirements to attempt to improve the viscosity and gravity characteristics of the fuel. The fuel was analyzed and the following characteristics were found to compare unfavorably with JP-5 requirements:

(1) Gravity - the gravity value was higher than the JP-5 requirement by a narrow margin. The higher gravity is related to the chemical composition of the fuel, which is primarily saturated fused ring compounds. Such compounds have a higher gravity than do the petroleum derived JP-5 constituents. However, the slight increase in gravity for the coal derived fuel would not be a problem in the operation of a gas turbine engine.

(2) Smoke Point - the value of 18 mm did not meet the requirement of 19 mm by a narrow margin. The low hydrogen content of 13 percent by weight (vice 13.5 percent for JP-5) is the cause of the unacceptable value. Additional hydrotreating during the refining of the fuel would correct this problem.

(3) Thermal Oxidation Stability - a breakpoint temperature of 249°C (480°F) was obtained for this fuel vice the JP-5 requirement of 260°C (500°F). The low thermal oxidation stability was believed to be the result of soluble metals (15 ppb copper, 38 ppb iron and 50 ppb zinc) present in the fuel. After removal of the soluble metals by clay treatment, the fuel had a break point temperature of 282°C (540°F).

(4) Particulate Matter - This fuel contained an unacceptable amount of sediment, which was probably due to the particulate matter in the drums used for shipping. The sediment was removed by mechanical filtration.

b. The change in the distillation range for the Phase II fuel (as compared to the equivalent Phase I fuel) did reduce the viscosity of the coal derived fuel to a value well within the range required by JP-5.

c. Further details on the tests conducted may be found in Appendix E.

6. Coalescer Performance of JP-5 Type Fuel (Phase II) Derived From Coal

a. This fuel was subjected to water coalescence tests in a single element testing system. The results obtained with the Phase II fuel were satisfactory and compared favorably with those obtained with JP-5.

b. A test in which a small amount of the Phase II fuel was combined with a large amount of JP-5 resulted in a detrimental effect on the water coalescing ability of the coalescer element. This area of work warrants further investigation.

c. Further details on the tests conducted may be found in Appendix F.

7. T63-A-5A Engine Performance and Exhaust Emission Tests Using JP-5 Type Fuel (Phase II) Derived From Coal

a. Engine Performance - A calibration test using JP-5 was performed on this engine prior to the evaluation of the coal derived fuel. The data showed the engine performance to conform to the model specification requirements. Following the calibration test, the coal derived fuel was evaluated and the engine performance data obtained were equivalent to the JP-5 data.

b. Exhaust Emissions - Measurements for carbon monoxide (CO), total unburned hydrocarbons (THC) and oxides of nitrogen (NO_x) in the exhaust stream were made for both JP-5 and the fuel derived from coal. Comparison of the data showed equivalent exhaust emissions for both fuels.

c. Further details on the tests conducted may be found in Appendix G.

8. The information concerning the processing performed by the Sun Oil Company to refine the JP-5 type fuels from coal syncrudes may be found in reference 6.

NAVFAC-PE-99

REFERENCES

1. AUTHORIZATION: NAVAIR AIRTASK No. A330-330-05PB-5F57-571-3 1, Development of Alternate Fuels for JP-5 Fuel, 24 June 1974.
2. CONTRACT: U.S. Navy Contract N00140-74-C-0568, of 24 June 1974, with Sun Oil Company of Pennsylvania.
3. LETTER: NAVFAC Letter 1L71:125-13340 Ser F014 of 1 February 1974.
4. TECHNICAL PAPER: Stage Flashed-Bed Hydrogenation of Coal at the Project CLEW Pilot Plant, Smith, D. L., et al, American Institute of Chemical Engineers 77th National Meeting, Pittsburgh, Pennsylvania, 2 June 1974.
5. AUTHORIZATION: NAVAIR AIRTASK No. A5365360-05PF-5W4543-0000, Work Unit Assignment No. 175-4P0-360, Evaluation of JP-5 Type Fuel Derived From Coal, 18 February 1975.
6. REPORT: Preparation of Gas Turbine Engine Fuel From Synthetic Crude Oil Derived from Coal - Phase II Final Report (USN Contract N00140-74-C-0568, Mod. P00101), Sun Oil Company, February 6, 1975.

UNITED STATES GOVERNMENT

Memorandum

PE71:JS:RJD:sds
10340

TO : C. J. Nowack

DATE: 22 January 1977

FROM : J. Solash, R. J. Delfosse

SUBJECT: NAVAIR WUP NAPTC-812 - Analysis of Phase I Coal Derived JP-5 Type Fuels

- REF : (a) Preparation of Gas Turbine Fuel From Synthetic Crude Oil Derived From Coal - Phase I, Sun Oil Company Report, 15 Oct 1974, Contract No. H00140-74-C-0568
(b) AFAPL-TR-72-103, Hydrogen Content as a Measure of the Combustion Performance of Hydrocarbon Fuels, May 1973
(c) NAVAIR WUA No. NAPTC-780-4R6-359; Development of JP-5 Icing Inhibitor and Biocide Additive, ltr of 23 June 1975

- ENCL : (1) Tables I through IV, inclusive
(2) Figure 1

1. Introduction. The Phase I requirement of the subject contract was to provide the Naval Air Propulsion Test Center (NAPTC) with four 0.04 m³ (10 gallon) samples of JP-5 type fuel having a low (0-5 percent volume) and high (20-25 percent) aromatic content from two synthetic crude oils derived from Utah and Western Kentucky coals. The synthetic crude oils were obtained from the FMC Corporation which used the COED process in their manufacture. The four fuel samples were analyzed by NAPTC to determine their properties and composition relative to Specification MIL-T-5624K (Grade JP-5). It was considered appropriate not to require full conformance to the JP-5 specification in view of current refinery processing technology limitations, the properties of the crude oils and the economical reasons. The results of the analysis of the Phase I samples were also used as the technical basis for selecting one of the four fuels that would be produced on a larger scale (approximately 0.95 m³ (250 gal)) in Phase II of the contract.

2. Conclusions.

a. The JP-5 type fuels refined from synthetic crudes derived from coal:

- (1) exhibit higher viscosity and lower API gravity values than are normal for petroleum base JP-5 fuels.
- (2) have freeze points that vary primarily with the source of the coal. The freeze points of the fuels varied from above to below the range for current petroleum base JP-5 fuels.
- (3) exhibited smoke point and thermal stability values that varied with the aromatic content of the fuel. The high aromatic content fuels had marginal thermal stability and poor smoke point values whereas the low aromatic fuels exhibited exceptional thermal stability values and acceptable



smoke point values when compared to those of current petroleum base JP-5 fuels.

(4) exhibited negligible trace soluble metal (Zn, Cu, Fe) content of less than 5 parts per billion (ppb).

(5) have a greater tendency to dissolve water than does conventional JP-5.

(6) respond to the addition of the Fuel System Icing Inhibitor (FSII) as does conventional JP-5.

b. Reduction of the distillation end point to 260°C (500°F) improves the viscosities of the high aromatic content JP-5 type fuels. The low aromatic content JP-5 type fuels were not studied in this respect, but would be expected to behave similarly.

c. The high aromatic content JP-5 type fuel refined from the synthetic crude oil derived from Western Kentucky coal represents the most practical fuel for further study because: (1) fuels from coal (for reasons of economy) will be high in aromatic content, and (2) it has a significantly better freeze point than does the corresponding Utah fuels.

3. Recommendations. The Phase II fuel should be refined from synthetic crude oil derived from Western Kentucky coal with:

a. an aromatic content in the range of 20-25 percent by volume.

b. a distillation end point of 260°C (500°F) to improve the viscosity and gravity characteristics.

4. Results and Discussion.

a. The test data from the Sun Oil Company report, reference (a), and the NAPTC laboratory for the four coal derived fuels are presented in Tables I through IV of enclosure (1). Comparison of the data from the two laboratories showed some inconsistencies. For the most part, however, the data were acceptable since the differences are within the precision of the test methods. There were two major disagreements in the data; the hydrogen content and the smoke point. The hydrogen content reported by Sun Oil Company was unmistakably too high due either to experimental error or an imprecise test method. The percent hydrogen of 14.78, 14.11 and 15.54 for samples 0002, 0003, and 0004 could only be representative of a highly paraffinic fuel ($C_{12}H_{26}$ = 15.3% H). Coal derived kerosenes are composed primarily of saturated fused ring structures represented by substituted alkyl decalins. For example, trimethyl decalin contains 13.4 percent hydrogen. Therefore, at the suggestion of NAPTC, Sun Oil Company reviewed their analytical procedure for the determination of hydrogen. It was found that the method employed by Sun was unsatisfactory for analyzing volatile materials that boil in the range up to 218°C (425°F). The samples were re-evaluated using a different technique (Pregl Method). The samples were also analyzed by an independent laboratory selected by the Sun Oil Company.

The average values of the hydrogen content were resubmitted to NAPTC and after comparison with the NAPTC data, the values were found to be acceptable. A compilation of the values for the hydrogen content from the various laboratories are listed as follows:

Sample No.	Values Originally Submitted By Sun Oil Company, %	Averaged Values Submitted By Sun Oil Company, %	NAPTC Values, %
0001	12.75	12.9	12.85
0002	14.78	12.8	13.40
0003	14.11	13.4	13.40
0004	15.54	13.3	13.10

* Averaged values from Sun and independent laboratory data.

The averaged hydrogen values of the coal derived fuels reported by Sun are acceptable and will be considered the more representative values.

b. The smoke point values for all coal derived fuels reported by Sun Oil Company were in complete disagreement with the NAPTC data. At the suggestion of NAPTC, both laboratories repeated the smoke point test and the original data reported by each laboratory were duplicated. Thus the problem of inconsistencies in the smoke point data between the two laboratories was not resolved. NAPTC ran additional studies which involved procedural and equipment checks using ASTM calibration fuels (isooctane-toluene blends). The results of the study indicated that the NAPTC laboratory equipment was functioning properly and the procedure employed was exactly as prescribed in the manual. Therefore, to make a judgment as to which data were more accurate, the smoke points for the coal derived fuels were calculated using the averaged hydrogen content values and the empirical equation: $H_2 = 4.54 + 3.03 \log_{10} (sp)$, where H_2 = percent hydrogen by weight and sp = the smoke point value in millimeters. This equation was obtained from reference (b). The calculated and the experimentally determined smoke points are as follows:

Fuel	Averaged % Hydrogen by weight	NAPTC Smoke Point Values, mm	Sun Oil Smoke Point Values, mm	Calculated Smoke Point, mm
0001	12.9	17	11	15.8
0002	12.8	17	11	15.3
0003	13.4	22	16	18.6
0004	13.3	22	26	18.0

A plot of these data is shown in figure 1 of enclosure (2) which also includes the NAPTC data for the calibration fuel blends. It can be seen that the NAPTC smoke point data are closer to the line of ideal correlation and exhibit a better trend than that of the Sun Oil data for the test fuels. Therefore, the NAPTC values are considered to be more accurate and will be utilized in lieu of the Sun Oil Company data.

c. The API gravity values of all the coal derived fuels were lower than the range of values normally obtained for JP-5 fuel. The reason for the low API gravity (high specific gravity) is the basic chemical composition of the fuel, which is made up mostly of derivatives of decalins. Decalin and its derivatives have specific gravities ranging from 0.872 (trans decalin) to 0.895 (cis decalin). Therefore, it is an accepted fact that JP-5 derived from coal will have a higher specific gravity than that of the petroleum derived fuel.

d. The high viscosity values of the coal derived fuels could be a drawback with respect to engine starting performance at low temperatures. The cause of the high viscosity is either the unusual chemical composition of the fuel or the high molecular weight compounds at the upper distillation temperature range, or both. It was found that a significant decrease in viscosity could be achieved by reducing the distillation end point of these fuels to 260°C (500°F). The high aromatic fuels (samples 0001 and 0002) were distilled to obtain an end point temperature of 260°C (500°F) with the following resulting change in viscosities of these fuels as measured at -34°C (-30°F).

	<u>Viscosity, Before Distillation, cSt</u>	<u>Viscosity, After Distillation, cSt</u>
0001	23.7	18.7
0002	22.9	19.3

It has not been determined what compounds were actually removed, other than "high boilers", by this distillation. This decrease in viscosity by limiting the fuel to an end point temperature of 260°C (500°F) is equally applicable to the low aromatic content fuels. This change in the end point temperature of the fuel will be incorporated into the Phase II refining of the larger quantity of fuel in an effort to provide a more representative JP-5 type fuel with respect to the viscosity.

e. The thermal oxidation stability characteristic of the low aromatic content fuels was extremely high, having breakpoint temperatures in the range of 371°C (700°F) and higher, as defined by the Jet Fuel Thermal Oxidation Test (JFTOT) procedure. The high breakpoint temperatures, which were the result of the severe two-stage hydrotreatment that the fuels had received, are not characteristic of conventional JP-5. Therefore, the Phase II fuel will not receive this severe level of hydrotreatment because this high degree of thermal oxidation stability is not required and a two-stage hydrotreatment is not a current refining procedure. The thermal oxidation stability of the high aromatic fuels is considered to be marginal. For example, the minimum temperature requirement of MIL-T-5624J is 270°C (500°F). Samples 0001 and 0002 had breakpoint temperatures of 257°C (495°F) and 263°C (505°F) respectively. Conventional JP-5 fuels on the average had breakpoint temperatures of about 279°C (535°F).

f. The soluble metal content of the coal derived fuel was investigated via atomic absorption spectroscopy. No copper or iron was found in any of the four samples, however, zinc was present at 4 ppb in all the samples. This amount of soluble zinc is not significant and does not contribute to

the fuel quality in any way.

g. The initial freeze point determinations made by NAPTC were complicated by the excessive quantities of water dissolved in the coal derived fuels. The excess quantities of free water produced at -34°C (-30°F) caused turbidity due to ice crystal formation thus giving false freeze point readings. The water was removed from the fuels by drying with 3A Molecular Sieve (Linde) or anhydrous magnesium sulfate, and the freeze points re-determined. The agreement between the two laboratories with respect to the freezing points was considered acceptable. The slight disagreement is believed to be the result of sampling. Sun Oil Company ran their analysis on selected stream samples from the hydrotreater, while NAPTC ran tests on the combined stream samples. Therefore, the fuel evaluated at NAPTC is a more representative sample, consequently the NAPTC data are more representative of a coal derived fuel.

h. The significant amount of dissolved water found in the coal derived fuel samples could detrimentally affect the fuel response to FSII present in the fuel. Therefore a low temperature pumping test of coal derived fuel with and without icing inhibitors was performed. The details of the test equipment are described in reference (c). Sample 0002 and a typical JP-5 fuel were selected for the low temperature pumping test and the resulting data obtained are as follows:

<u>Fuel</u>	<u>Dissolved Water Content, ppm</u>	<u>FSII Content, % Volume *</u>	<u>Fuel/Filter Icing Temperature, $^{\circ}\text{C}$ ($^{\circ}\text{F}$)</u>
JP-5	75	-	-14 (+7)
	75	0.0156	-26 (-14)
Sample 0002	102	-	-12 (+11)
	102	0.0156	-23 (-10)

* Ethylene glycol monomethyl ether.

The data indicated that despite the higher concentration of dissolved water in the coal derived fuel, the decrease in the fuel/filter icing temperature for both fuels was identical (12°C (21°F)). This result is contradictory in that it would be expected that the fuel with the greater water content would display a smaller decrease in fuel/filter icing temperature because of the greater amount of water available. The data for the uninhibited fuels do show the effect of the water content, with the 0002 fuel having a 2°C (4°F) higher fuel/filter icing temperature than does the JP-5. It can only be theorized at this time that the identical decrease in fuel/filter icing temperature for both fuels was caused by different water/fuel solubility characteristics versus temperature or lack of sensitivity of the test equipment.

R. J. Delforse for

J. SOLASH

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R. J. DELFORSE

TABLE 1
SPECIFICATION ANALYSIS OF PHASE I JP-5 TYPE FUEL DERIVED FROM COAL
Fuel: No. 0001, High Aromatic (20-25 vol %); Coal Source: Westein Kentucky

TEST	ASTM STANDARD	SPECIFICATION MIL-T-5624K REQUIREMENTS	RESULTS	
			SUN OIL COMPANY	NAPTC
Distillation Temperature, °C (°F)	D-86			
Initial Boiling Point		Report	188 (371)	202 (394)
10%		205 (401) max	212 (414)	213 (416)
20%		Report	217 (423)	219 (426)
50%		Report	234 (453)	237 (459)
90%		Report	266 (510)	267 (513)
End Point		290 (554) max	279 (535)	283 (542)
Residue, vol %		1.5 max	1.0	1.0
Loss, vol %		1.5 max	1.0	0.0
Gravity, °API	D-287	36 min/48 max	30.8	30.2
Freezing Point, °F	D-2106	-46 (-51) max	-56 (-68)	-48 (-54)
Aromatics, vol %	D-1319	25.0 max	22.7	24.8
Smoke Point, mm	D-1322	19 min	11	17.0
Flash Point, °C (°F)	D-93	60 (140) min	80 (176)	80 (176)
Existent Gum, mg/100 ml	D-381	7 max	2	0.0
Sulfur, Wt. %	D-1266	0.4 max	< 0.001	0.05
Thermal Stability	D-3241	Pass at 260°C (500°F)	-	Pass at 257°F (495°F)
Heating Value, kJ/kg (BTU/lb)	D-240	42.6 (18,300) min	43.0 (18,470)	42.6 (18,294)
Viscosity, cSt @ -34°C (-30°F)	D-445	16.5 max *	23.5	23.69
Olefins, vol %	D-1319	5.0 max	1.1	1.0
Particulate Matter, mg/l	D-2276	1.0 max	0.04	1.0
Total Acid No.	D-974	0.015 max	0.001	-
Nitrogen, Wt. %	-	N/A	< 0.05	-
Carbon, Wt. %	-	N/A	86.82	89.00
Hydrogen Wt. %	-	N/A	12.75	12.95

*Value taken from MIL-T-5624J.

TABLE II

SPECIFICATION ANALYSIS OF PHASE I JP-5 TYPE FUEL DERIVED FROM COAL

Fuel: No. 0003, High Aromatic (20-25 vol%); Coal Source: Utah

TEST	ASTM STANDARD	SPECIFICATION MIL-T-5624K REQUIREMENTS	RESULTS	
			SUN OIL COMPANY	MAFC
Distillation Temperature, °C (°F)				
Initial Boiling Point	D-86	Report	207 (405)	209 (409)
100		205 (401) max	217 (421)	219 (426)
200		Report	221 (430)	223 (434)
500		Report	236 (454)	238 (460)
900		Report	262 (503)	264 (508)
End Point		290 (540) max	286 (541)	279 (535)
Residue, vol %		1.5 max	1.0	1.2
Loss, vol %		1.5 max	1.0	0.0
Gravity, °API	D-287	16 min/40 max	12.8	12.4
Freezing Point, °C (°F)	D-2386	-46 (-51) max	-43 (-46)	-40 (-40)
Aromatics, vol %	D-1319	25.0 max	21.8	24.1
Smoke Point, mm	D-1322	19 max	11	17.0
Flash Point, °C (°F)	D-93	60 (140) min	99 (176)	81 (174)
Existent Gum, mg/100 ml	D-181	7 max	1	0.1
Sulfur, Wt. %	D-1266	0.4 max	< 0.001	0.04
Thermal Stability	D-1241	Pass at 260°F (500°C)	-	Pass at 261°C (505°F)
Heating Value, MJ/KG (BTU/lb)	D-240	42.6 (18,300) min	-	42.7 (18,172)
Viscosity, cSt @ -34°C (-30°F)	D-445	16.5 max	22.52	22.94
Olefins, vol %	D-1319	5.0 max	0.3	1.20
Particulate Matter, mg/l	D-2276	1.0 max	0.4	1.45
Total Acid No.	D-974	0.015 max	0.2	-
Nitrogen, Wt. %	-	N/A	0.27	-
Carbon, Wt. %	-	N/A	94.14	94.70
Hydrogen, Wt. %	-	N/A	14.79	11.40

NAFTO-PE-93

a value taken from MIL-T-5624J.

TABLE III
SPECIFICATION ANALYSIS OF PHASE I JP-5 TYPE FUEL DERIVED FROM COAL

Fuel: No. 0003 Low Aromatic (0-5 vol %); Coal Source: Western Kentucky

TEST	ASTM STANDARD	SPECIFICATION MIL-T-5624F REQUIREMENTS	RESULTS	
			SUN OIL COMPANY	NAPTC
Distillation Temperature, °C (°F)	D-86			
Initial Boiling Point		Report	199 (399)	200 (392)
10%		205 (401) max	212 (413)	213 (416)
20%		Report	217 (423)	219 (426)
50%		Report	235 (455)	238 (460)
90%		Report	269 (515)	270 (518)
End Point		290 (560) max	277 (530)	286 (546)
Residue, vol %		1.5 max	0.4	1.0
Loss, vol %		1.5 max	1.6	0
Gravity, °API	D-287	16 min/40 max	32.4	31.8
Freezing Point, °C (°F)	D-2386	-46 (-51) max	-54 (-65)	-50 (-58)
Aromaticity, vol %	D-1319	25.0 max	3.1	4.69
Smoke Point, mm	D-1322	19 min	16	22
Flash Point, °C (°F)	D-93	60 (140) min	76 (168)	79 (174)
Existent Gum, mg/100 ml	D-381	7 max	1	0
Sulfur, Wt. %	D-1266	0.4 max	0.0001	0.005
Thermal Stability	D-3261	Pass at 260°C (500°F)	-	Pass at 371°C (700°F)
Heating Value, MJ/kg (BTU/lb)	D-240	42.6 (18,300) min	-	42.8 (18,343)
Viscosity, cSt @ -34°C (-30°F)	D-445	16.5 max *	25.52	25.95
Olefins, vol %	D-1319	5.0 max	2.8	1.56
Particulate Matter, mg/l	D-2276	1.0 max	0.19	0.93
Total Acid No.	D-974	0.015 max	0.205	-
Nitrogen, Wt. %	-	N/A	0.13	-
Carbon, Wt. %	-	N/A	95.75	95.6
Hydrogen, Wt. %	-	N/A	14.11	13.4

*Value taken from MIL-T-5624J.

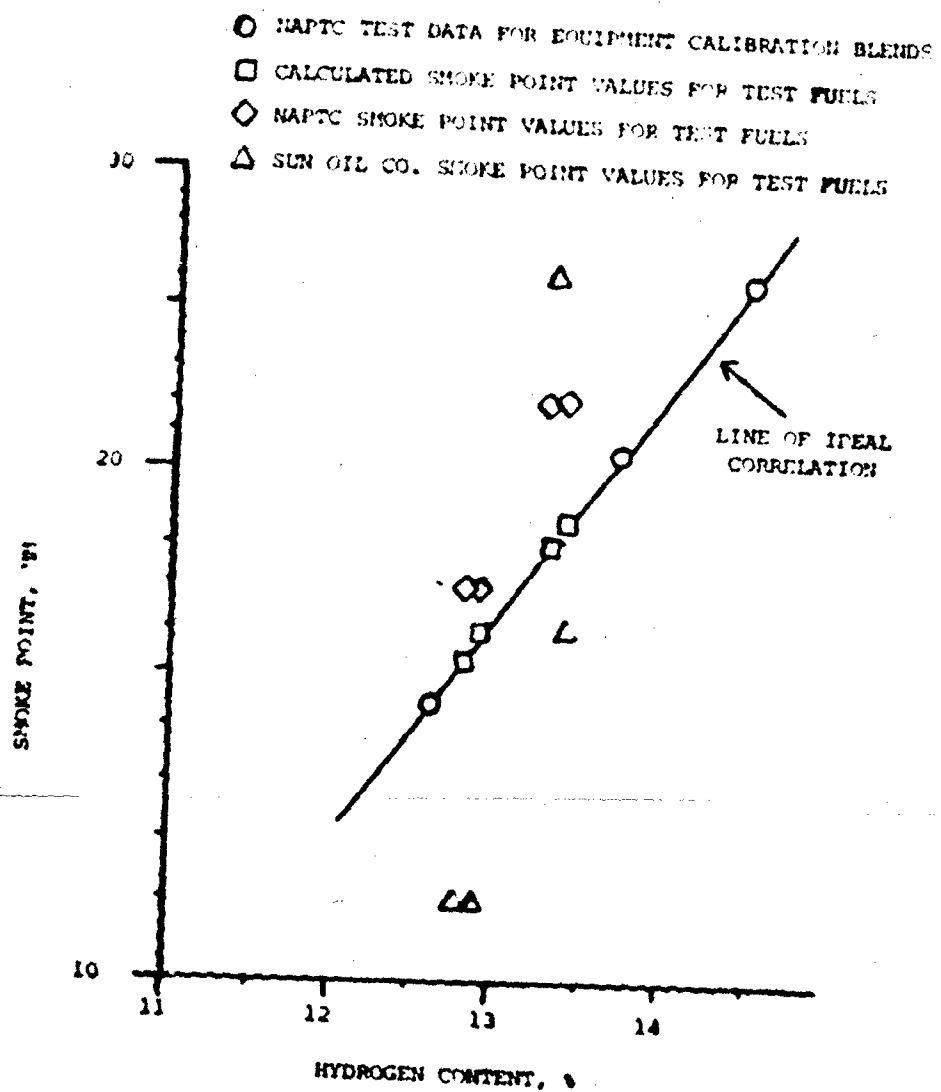
ENCLOSURE (1)

TABLE IV
SPECIFICATION ANALYSIS OF PHASE 1 JP-5 TYPE FUEL (LITER 10.0) AN
Fuel: No. 0004, Los Arromatic (0-5 vol. %): Coal Sources: Utah

TEST	ASTM STANDARD	SPECIFICATION MIL-T-5624K REQUIREMENTS	TEST RESULTS	UNIT
Distillation Temperature, °C (°F)	D-86			
Initial Boiling Point		Report	204	°C
10%		205 (401) max	207	°C
20%		210 (402) max	210	°C
50%		Report	242	°C
90%		Report	276	°C
End Point		Report	303	°C
Residue, vol %		290 (540) max	292	vol %
Loss, vol %		1.5 max	1.2	
		1.5 max	1.2	
Gravity, °API	D-287	16 min 49 max	14.7	°API
Freezing Point, °F	D-146	-40 (-51) max	-40	°F
Aromatics, vol %	D-1119	20.0 max	20.0	vol %
Smoke Point, °C (°F)	D-1312	19 max	20	°C
Flash Point, °C (°F)	D-93	60 (145) min	80	°C
Existent Gum, mg/100 ml	D-291	5 max	5	mg/100 ml
Sulfur, wt. %	D-1206	0.4 max	0.3	wt. %
Thermal Stability	(-124)	Pass at 200° (200°)	Pass	
Heating Value, MJ/kg (BTU/LB)	D-242	42.6 (18,100) min	42.6	MJ/kg
Viscosity, cSt @ 14°C (10°F)	D-445	16.5 max	16.5	cSt
Defines, vol %	D-1314	5.0 max	5.0	vol %
Particulate Matter, mg/l	D-1314	1.0 max	1.0	mg/l
Total Acid No.	D-974	0.015 max	0.015	
Sulfuric Acid, wt. %	-	NA	NA	
Corrosion, wt. %	-	NA	NA	
Water, wt. %	-	NA	NA	

Analysis taken from MIL-T-5624K.

FIGURE 1. VARIATION IN SMOKE POINT VALUES FOR FUEL DERIVED FROM COAL



UNITED STATES GOVERNMENT

Memorandum

PE71:JS:sds
10340

DATE: 22 January 1977

TO : C. J. Nowack

FROM : J. Solash

SUBJECT: NAVAIR WUP No. NAPTC-812 - Storage Stability Characteristics of JP-5 Type Fuels (Phase I) Derived From Coal

ENCL : (1) Tables I and II

1. Introduction. JP-5 frequently is stored for extended periods (years) in the field and therefore must be resistant to chemical change in order to be useable in aircraft propulsion systems after such storage. With the probable future usage of fuels derived from synthetic crudes, which will differ in chemical composition from current JP-5, it is necessary to evaluate their storage characteristics in order that any instability problems can be rectified. For this reason, four JP-5 type fuels refined from synthetic crudes derived from coal were evaluated to determine their accelerated storage stability characteristics. The fuel parameters tested were thermal oxidative stability and existent gums. The fuels were low (0 to 5 percent) and high (20 to 25 percent) aromatic content samples derived from both Utah and Western Kentucky coals. Liquifaction of the coal into synthetic crudes was performed by FMC Corporation using the Char Oil Energy Development (COED) process. The fuel samples were refined by the Sun Oil Company from the synthetic crudes by high pressure hydro-treatment processing.

2. Conclusions. After storing the coal derived JP-5 type fuels for 26 weeks at 43°C (110°F), it was determined that:

a. there was no degradation of their thermal oxidation stability characteristics.

b. one of the four fuels exhibited a significant increase in gum content.

c. they were compatible with an oxidation inhibitor, which also eliminated the significant increase in gum content which occurred with one of the neat fuels.

3. Recommendation. The mandatory addition of an oxidation inhibitor to JP-5 fuel derived from coal should be considered for storage stability purposes when a specification for such fuels is developed.

4. Description of the Test Fuels: The coal derived fuels that were tested are identified as follows:



<u>Sample Number</u>	<u>Coal Source</u>	<u>Aromatic Content, Vol. %</u>
0001	Western Kentucky	24.8
0002	Utah	24.1
0003	Western Kentucky	4.7
0004	Utah	6.1

5. Method of Test. The experimental details of the test for each fuel are as follows:

a. Three litres (0.79 gal) of fuel were added to each of four 3.8 litre (1 gal) cans which were lined with an inert resin coating.

b. A 1020 steel (cold rolled black iron) specimen and/or an oxidation inhibitor were added to three of the cans to determine their compatibility with the fuel, resulting in the following arrangement:

(1) Can containing fuel only.

(2) Can containing fuel and black iron specimen.

(3) Can containing fuel and oxidation inhibitor.

(4) Can containing fuel, black iron specimen and oxidation inhibitor.

c. The black iron specimen had a surface area of 37.4 square centimeters (5.8 square inches) and was cleaned by degreasing with benzene.

d. The oxidation inhibitor, 2,4-dimethyl-6-t-butyl phenol was added at the prescribed maximum concentration of 24 mg/l (8.4 pounds/1000 barrels).

e. The cans were maintained at a temperature of 43°C (110°F). Every two weeks they were uncapped, cooled and reheated (total period of 24 hours) to permit the introduction of fresh air into the container vapor space. The fuels were then recapped and the test resumed.

f. The test was conducted for 26 weeks after which the fuel samples were evaluated for thermal oxidation stability, using the Alcor Jet Fuel Thermal Oxidation Tester (JFTOT), ASTM D-3241 and gum content (in duplicate) using test method ASTM D-391.

6. Results and Discussion.

a. Thermal Oxidative Stability - This characteristic of the test fuels was measured before and after the 26 week test. The thermal oxidative stability breakpoint temperature was established for each of the fuels before storage by increasing the JFTOT test temperature until a failure was achieved. By establishing the breakpoint temperature before and after the storage test, the magnitude of degradation can be determined. As can be seen from the data obtained, Table I of enclosure (1), no degradation occurred so that it was not deemed necessary to establish the breakpoint temperatures for all the fuel samples after the storage test. Reviewing

the data for sample number 0001, storage apparently has a beneficial effect upon the fuel and there are no compatibility problems with the black iron or oxidation inhibitor. The data for sample 0002 are slightly different from that of sample 0001 in that the neat fuel and the fuel/black iron sample show no change in breakpoint temperature (a change of 3°C (5°F) is insignificant and within the repeatability of the test). The presence of the oxidation inhibitor produces approximately the same improvement in breakpoint temperature as occurred with sample number 0001. Sample 0003 had such a high breakpoint temperature that it was only feasible to rerun the maximum temperature tested before storage. In this case, it cannot be determined whether or not degradation occurred. The breakpoint temperature data for sample number 0004 indicate that no degradation occurred due to storage and that some improvement is probable. Overall, the storage stability of these fuels derived from coal with respect to thermal oxidative stability appears to be excellent.

b. Existent Gum Content - The gum content values obtained for the various fuel samples before and after the storage test are shown in Table II of enclosure (1). Other than sample 0002, the gum content changes during storage for the various fuels are not considered to be a problem. The 10.2 mg/100 ml of fuel increase in gum content of sample 0002 fuel containing the black iron is considered significant as it would eventually exceed the 14 mg/100 ml of fuel limit for service fuels. This particular test sample was stored in the laboratory at room temperature for an additional eight weeks after which the gum content was found to be 48 mg/100 ml of fuel. It is readily apparent however, that the presence of the oxidation inhibitor eliminates this gum formation problem. It is also significant to note that the gum content problem for sample 0002 was also eliminated by the additional refining step performed to produce sample 0004 (both samples refined from the same synthetic crude derived from Utah coal). Overall it would appear to be necessary to add an oxidation inhibitor to these fuels derived from coal to achieve storage stability with respect to their gum content.



J. SOLASH

TABLE I

EFFECT OF STORAGE ON THERMAL OXIDATION STABILITY OF COAL DERIVED FUELS

SAMPLE NUMBER	CONSTITUENT ADDED TO FUEL	BREAKPOINT TEMPERATURE, °C (°F)			
		BEFORE STORAGE		AFTER STORAGE	
0001	-	257	(495)	282	(540)
	Black Iron	257	(495)	>277	(530)
	Oxidation Inhibitor	257	(495)	>277	(530)
	Oxidation Inhibitor/ Black Iron	257	(495)	>291	(555)
0002	-	263	(505)	260	(500)
	Black Iron	263	(505)	263	(505)
	Oxidation Inhibitor	263	(505)	285	(545)
	Oxidation Inhibitor/ Black Iron	263	(505)	>288	(550)
0003	-	>371	(700)	>371	(700)
	Black Iron	>371	(700)	>371	(700)
	Oxidation Inhibitor	>371	(700)	>371	(700)
	Oxidation Inhibitor/ Black Iron	>371	(700)	>371	(700)
0004	-	368	(695)	>371	(700)
	Black Iron	368	(695)	371	(700)
	Oxidation Inhibitor	368	(695)	371	(700)
	Oxidation Inhibitor/ Black Iron	368	(695)	>366	(690)

TABLE IIEFFECT OF STORAGE ON EXISTENT GUM FORMATION OF COAL DERIVED FUELS

<u>SAMPLE NUMBER</u>	<u>CONSTITUENT ADDED TO FUEL</u>	<u>BEFORE STORAGE</u>	<u>AFTER STORAGE</u>	<u>CHANGE</u>
0001	-	0.0	0.6	+0.6
	Black Iron	0.0	0.2	+0.2
	Oxidation Inhibitor	0.0	0.0	0.0
	Oxidation Inhibitor/ Black Iron	0.0	0.4	+0.4
0002	-	0.1	2.6	+2.5
	Black Iron	0.1	10.3	+10.2
	Oxidation Inhibitor	0.1	0.0	-0.1
	Oxidation Inhibitor/ Black Iron	0.1	0.8	+0.7
0003	-	0.0	1.8	+1.8
	Black Iron	0.0	0.1	+0.1
	Oxidation Inhibitor	0.0	0.1	+0.1
	Oxidation Inhibitor/ Black Iron	0.0	1.3	+1.3
0004	-	0.1	1.2	+1.1
	Black Iron	0.1	0.9	+0.8
	Oxidation Inhibitor	0.1	0.0	-0.1
	Oxidation Inhibitor/ Black Iron	0.1	1.6	+1.5

UNITED STATES GOVERNMENT

Memorandum

PE71:RJD:sds

10340

DATE: 22 January 1977

TO : C. J. Nowack

FROM : R. J. Delfosse

SUBJECT: NAVAIR WUP NAPTC-812 - Exposure of JP-5 Type Fuels Derived From Coal to Copper Surfaces; effect on thermal oxidation stability of

1. Introduction. Small quantities (37.8 liters (10 gallons)) of coal derived JP-5 type fuels were provided by the Sun Oil Company through Contract No. N00140-74-C-0568, Mod. P00001. These fuels have been extensively studied with respect to their physical and chemical properties (Appendix A). However, since these fuels have a different chemical composition from petroleum derived JP-5, their investigation must go beyond standard testing. One such area of concern is the compatibility of these fuels with metal surfaces that are wetted by the fuel. This investigation covers the compatibility of these coal derived fuels with copper. It is known that current JP-5 degrades in thermal oxidative stability when subjected to copper surfaces. The main thrust of this work was to determine what effect the exposure to copper will have on the thermal oxidation stability characteristics of the fuels derived from coal. This information is of paramount importance since copper is one of the metals used in the construction of fuel handling systems on aircraft carriers.

2. Conclusions.

a. Copper migrates as a fuel soluble metallic complex into the JP-5 type fuels derived from coal at a significant rate.

b. The rate of copper migration was found to be a function of the hydrotreatment level used for refining of the coal syncrudes. The higher aromatic content fuels (single stage hydrotreatment) produced higher copper migration rates than did the low aromatic content fuels (two stage hydrotreatment).

c. The coal derived JP-5 type fuels exhibited higher and lower copper migration rates than did a current JP-5 fuel. The higher rates occurred with the high aromatic content fuels and the lower rates occurred with the low aromatic content fuels.

d. The thermal oxidation stability of all fuels derived from coal and the current JP-5 fuel were adversely affected by a soluble copper concentration of 200 parts per billion (ppb).

3. Recommendations.

a. Copper passivators such as benzotriazole should be investigated as



C-1

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a fuel additive to eliminate copper contamination of fuels derived from coal when exposed to copper surfaces.

b. The possible reduction in thermal oxidation stability of fuels derived from coal during long periods of exposure to other metals, specifically iron, should be investigated.

4. Description of Test Fuels. The coal derived fuels tested were identified as samples numbers 0001 through 0004. A general description of the fuels is as follows:

<u>Identification</u>	<u>Coal Source</u>	<u>Aromatic Content Vol. %</u>	<u>Distillation Range, °C, (°F)</u>
0001	Western Kentucky	24.8	202-383 (396-542)
0002	Utah	24.1	209-279 (408-535)
0003	Western Kentucky	4.7	200-286 (392-546)
0004	Utah	6.1	207-282 (404-539)

5. Method of Test.

a. Cleaned copper specimens having a constant surface area were exposed to an exact volume of each the test fuels, and the rate of copper migration (fuel soluble copper complex) was measured as a function of time. The criterion used to determine the relative severity of copper solubilization of the fuel was to record the time required to reach 200 ppb soluble copper.

b. The experimental details used to measure the rate of copper migration are as follows:

(1) Copper Surface Area to Fuel Volume - Twelve copper specimens, each having a dimension of 25.4 mm (1 inch) by 101.6 mm (4 in) by 1.58 mm (1/16 in) were suspended vertically in a polypropylene beaker containing 1.97 litres (0.52 gal) of test fuel. This arrangement resulted in 2825 mm² of copper surface to 1 liter of fuel or 199 in²/gal.

(2) Copper Surface Preparation - Prior to immersing the specimens in the fuel, each specimen was cleaned by rubbing the surface with steel wool until a bright finish was produced. This step was followed by an isopropanol rinse. The specimens were then dried under vacuum.

(3) Fuel Environment and Sampling - The test was conducted at room temperature and under dynamic conditions which were produced by the stirring action of a magnetic stirrer employing a teflon coated bar. The stirring rate was arbitrarily set at a moderate rate in order to prevent the stirring bar from becoming misaligned or producing vibration. Also the rate was sufficient to avoid excessive heating of the fuel by the magnetic stirrer. The rate of stirring was maintained constant for all determinations. The test fuels were analyzed for soluble copper at one hour intervals, by aspirating the fuel directly into the Atomic Absorption Spectrophotometer. The fuel samples were aspirated from the center of the beaker midway between

the fuel surface and the bottom of the beaker to eliminate concentration gradients.

(4) Determination of Fuel Copper Content - Soluble copper determinations were made using a Perkin Elmer Spectrophotometer, Model 403. Copper concentration standards were prepared from 500 ppm copper as Bis (1 phenyl-1, 3 butanedione) Copper II contained in an oil matrix. This standard was purchased from F and J Scientific, Monroe, Connecticut. The hydrocarbon diluent for preparing the various copper concentrations was the actual test fuel after it had been clay treated to remove any trace of soluble copper. Copper standards were prepared for each test fuel.

d. The effect of soluble copper on the fuel thermal oxidation stability was measured at a constant concentration of copper, 200 ppb. The thermal oxidation stability breakpoint temperature was determined by use of the Alcor Jet Fuel Thermal Oxidation Tester (JFTOT) employing the test procedure outlined in ASTM D-3241. The thermal oxidation stability breakpoint temperature is the maximum test temperature at which satisfactory results are obtained.

6. Discussion of Results.

a. The rates at which copper migrated into the fuels derived from coal and the current JP-5 are as follows:

<u>Sample No.</u>	<u>Coal Source</u>	<u>Aromatic Content Vol. %</u>	<u>Time (hours to reach 200 ppb soluble copper)</u>
0001	Western Kentucky	24.8	22
0002	Utah	24.1	35
0003	Western Kentucky	4.7	80
0004	Utah	6.1	120
Reference JP-5	-	13.0	42

It can be observed that the coal derived fuels with high aromatic contents solubilized 200 ppb copper in a shorter period than did the reference JP-5 and the low aromatic content fuels derived from coal. It can also be noted that the low aromatic content fuels produced the lowest rates of copper migration of all the fuels. The apparent explanation for this mild attack by the low aromatic fuels is that the high degree of hydrotreatment to which they were submitted removed the polar compounds responsible for copper solubilization. In refining the crude to produce fuel with an aromatic level of 0-5 percent by volume, the non-hydrocarbon or polar compounds were converted to hydrocarbons.

b. The thermal oxidation stability of the fuels derived from coal and the current JP-5 was detrimentally affected by the presence of 200 ppb soluble copper. This effect was observed by comparing the thermal oxidation stability breakpoint temperatures of the fuels determined before the test and when the fuels contained 200 ppb copper. The data are as follows:

Sample No.	Breakpoint Temperature, No Copper Added °C, (°F)		Breakpoint Temperature, 200 ppb Copper, °C, (°F)	
0001	257	(495)*	210	(410)*
0002	266	(510)*	<199	(390)**
0003	>371	(700)*	<302	(575)**
0004	386	(695)*	<332	(630)**
JP-5 Reference	320	(575)*	238	(460)*

* Preheater Tube Rating Failure.

** Pressure Drop Rating Failure.

In several cases the breakpoint temperatures were listed as less than some value because the thermal oxidation stability testing had to be terminated at that value because of the lack of fuel. However, the data that were obtained clearly showed that the breakpoint temperature of each fuel regardless of its original thermal oxidation stability value is significantly lowered by the presence of 200 ppb soluble copper.

c. The ability of copper passivators to prevent the copper contamination of fuel derived from coal should be investigated in order to be able to correct this deficiency if it would become operationally required. Benzotriazole, a copper passivating additive, has been laboratory and service tested successfully with current JP-5 fuel.

R. J. Delfosse
R. J. DELFOSSÉ

UNITED STATES GOVERNMENT

Memorandum

PE71:CJN:sds

10340

DATE: 22 January 1977

TO : L. Maggitti

FROM : C. J. Nowack

SUBJECT: NAVAIR WUA No. NAPTC-175-4R6-386 - Elastomeric Material Compatibility Studies With JP-5 Type Fuels (Phases I and II) Derived From Coal

REF : (a) NAPTC Work Request N62376-75-WR00042 of 27 November 1974

ENCL : (1) Table I

1. Introduction. Samples of coal derived fuels were evaluated in regard to their compatibility with air frame and engine fuel system elastomers representative of the S3A aircraft. The work was performed by the Naval Air Development Center (NADC), Warminster, PA in accordance with reference (a). This report contains the results of the NADC tests.

2. Conclusion. The coal derived fuels had satisfactory compatibility with the elastomers tested.

3. Recommendation. Additional tests should be performed to assure the compatibility of coal derived fuels with the elastomeric materials used in other Navy aircraft.

4. Description.

a. The elastomeric materials (polymers) tested were as follows:

(1) Polymer "A" - FS Standard (LS-63U) - Formulated and cured as described Fluorosilicone Polymer in USAF Bulletin 539.

(2) Polymer "B" - FA Standard (Viton A) - Formulated and cured as described Fluorocarbon Polymer in USAF Bulletin 539.

(3) Polymer "C" - PR-1422 - MIL-S-8802 Sealing Compound, Temperature Resistant, Integral Fuel Tanks and Fuel Cell Cavities, High Adhesion.

(4) Polymer "D" - PR-702 - Channel Sealant - Sealing Compound Non-Curing, Groove Injection for Integral Fuel Tanks.

(5) Polymer "E" - PR-1560 - MIL-C-27725 - Coating, Corrosion Preventative, for Aircraft Integral Fuel Tanks.

b. The test fuels are identified in the following table.



<u>Fuel Identification</u>	<u>Aromatic Content, % Vol.</u>	<u>Coal Source</u>
0001	24.8	Western Kentucky
0002	24.1	Utah
0003	4.7	Western Kentucky
0004	6.1	Utah
0005	24.0	Western Kentucky
Control (JP-5)	13.0	N.A.

5. Method of Test. Elastomer test specimens were immersed into each of the test fuels for a period of 28 days. The fuel temperature was maintained at 49°C (120°F). After 28 days the specimens were evaluated for changes in properties in accordance with ASTM Method D-471-72. The elastomeric physical properties investigated were:

- a. Durometer hardness - Shore, Type A.
- b. Volume, % change in.
- c. Specific Gravity, % change in.
- d. Visual inspection for blisters, cracking or softening.

6. Analysis and Discussion of Results. The data resulting from the immersion tests of the five specimens in the test fuels are given in Table I of enclosure (1). An interpretation of the data was provided by private communication with the materials personnel at NADC. It was their opinion that the five synthetic fuels had no adverse effects on the elastomers, when compared to the results obtained with the petroleum derived JP-5 control fuel. There were no significant differences in the data that would indicate incompatibility of the fuels derived from coal with the elastomers used in the S3A aircraft air frame and engine.



C. J. NOWACK

TABLE I
COMPATIBILITY OF ELASTOMERS/SEALANTS (S3A AIRCRAFT)
WITH COAL DERIVED JP-5 TYPE FUELS

	<u>0001</u>	<u>0002</u>	<u>0003</u>	<u>0004</u>	<u>0005</u>	<u>JP-5</u>
<u>Polymer "A"</u>						
Volume Change, %	8.3	8.0	8.5	7.0	9.8	9.8
Specific Gravity, Change	-0.05	-0.05	-0.05	-0.04	-0.06	-0.06
Hardness Points, Change	-6	-7	-6	-6	-5	-7
<u>Polymer "B"</u>						
Volume Change, %	3.5	4.0	3.7	4.2	3.5	5.7
Specific Gravity, Change	-0.06	-0.05	-0.05	-0.05	-0.04	-0.06
Hardness Points, Change	-3	-3	-2	-3	-2	-3
<u>Polymer "C"</u>						
Volume Change, %	3.5	3.1	1.6	1.6	5.1	3.4
Specific Gravity, Change	-0.03	-0.02	-0.01	-0.01	-0.04	-0.01
Hardness Points, Change	-2	-2	0	-1	-3	-2
<u>Polymer "D"</u>						
Volume Change, %	5.3	3.6	1.6	0.7	5.6	3.8
Specific Gravity, Change	-0.03	-0.01	-0.01	-0.01	-0.03	-0.02
Hardness Points, Change	N/A	N/A	N/A	N/A	N/A	N/A

Polymer "E"

Polymer showed no evidence of blistering, cracking or softening with any of the test fuels.

UNITED STATES GOVERNMENT

Memorandum

PE71:JS:RJS:sds
10340

DATE: 22 January 1977

TO : C. J. Nowack

FROM : J. Solash, R. J. Delfosse

SUBJECT: NAVAIR WUA No. NAPTC-175-4R6-386 - Analysis of JP-5 Type Fuel (Phase II)
Derived From Coal

REF : (a) Specification MIL-T-5624K, Grade JP-5
(b) Preparation of Gas Turbine Engine Fuel From Synthetic Crude Oil
Derived from Coal, Phase II Final Report, Sun Oil Company

ENCL : (1) Tables I and II

1. Introduction. As recommended in Appendix A, 0.95 metre³ (250 gallons) of a high aromatic content fuel were refined by the Sun Oil Company (Contract NO0140-74-C-0568, Mod. P00001), from syncrude derived from Western Kentucky coal. Having established the deficiencies (in comparison to the requirements of reference (a)), of a similar 0.004 m³ (10 gal) sample of this fuel, the distillation end point for this fuel was changed to 260°C (500°F) vice 279°C (535°F) in order to improve the viscosity and gravity characteristics. This report provides the physical and chemical analyses that were performed on this Phase II sample of JP-5 type fuel derived from coal.

2. Conclusions.

a. The Phase II fuel compared favorably to the JP-5 requirements (reference (a)) in all characteristics except gravity, smoke point, thermal oxidation stability and particulate matter.

(1) The particulate matter and thermal oxidation stability characteristics can be improved to the levels required by reference (a) by conventional and clay filtration techniques, respectively.

(2) The smoke point can be improved to the level required by reference (a) by additional hydrotreatment of the fuel during the refining process.

(3) The higher density is inherent in the composition of the fuel and would be impractical to change since it should not be detrimental to engine operation.

b. Decreasing the distillation end point of the fuel (as compared to the original 0.004 m³ (10 gal) sample) significantly improved the viscosity, gravity and freeze point, and decreased the flash point of the fuel.

3. Recommendations. This fuel should be subjected to:



- a. a short engine test to evaluate its effect upon engine performance.
- b. engine and fuel system component type tests to determine any detrimental effects on component performance.

4. Analysis and Discussion of Results.

a. The Phase II, high aromatic fuel derived from a Western Kentucky coal was analyzed and the data obtained are given in Table I of enclosure (1). Corresponding data from the Sun Oil Company analysis, reported in reference (b), as well as the JP-5 requirements (reference (a)) are also given in Table I for comparison purposes. Both laboratories show reasonable agreement with the exception of the smoke point data. The NAPTC smoke point data are believed to be more accurate based upon the analysis performed in Appendix A.

b. The Phase II coal derived fuel compared favorably to the JP-5 requirements (reference (a)) in all characteristics except gravity, smoke point, thermal oxidation stability and contamination. The latter property is not significant since particulate matter can easily be removed from the fuel by conventional filtering methods. The smoke point and gravity, however, are related to basic chemical composition of the fuel. A refined coal derived fuel is composed of fused saturated polynuclear aromatics such as decalin. These compounds have much higher gravity than the compounds normally found in petroleum. Therefore, fuels derived from coal will normally have higher gravity values than do petroleum fuels. The smoke point is slightly below the JP-5 limit. The hydrogen content of the fuel, 13 percent by weight is undoubtedly responsible for the low smoke point. Reviewing Appendix A, it can be seen that the low aromatic fuel derived from Western Kentucky coal had a hydrogen content of 13.4 percent and a smoke point value of 22 mm. It is therefore indicated that additional hydrogen treatment of the Phase II fuel is required to improve its smoke point.

c. The thermal oxidation stability breakpoint temperature was determined to be 249°C (480°F) which is 11°C (20°F) below the JP-5 requirement. An analysis of the fuel for soluble metals revealed the presence of 15 ppb copper, 38 ppb iron, and 50 ppb zinc. The equivalent Phase I high aromatic fuel, on the other hand, had no detectable soluble metals present, and had a 260°C (500°F) thermal oxidation stability breakpoint temperature. Therefore, it can be projected that high aromatic fuel derived from coal will have marginal thermal oxidation stability characteristics and that the slightest soluble contamination, such as soluble metals, will cause this characteristic to become deficient. The Phase II fuel was clay treated to remove the soluble metals. This treatment resulted in an increase of the thermal oxidation stability breakpoint temperature to 282°C (540°F). This was a significant increase, when compared to the 260°C (500°F) value for the Phase I fuel. The clay treatment probably removed the soluble metals and non-hydrocarbon deposit precursors as well.

d. The properties of the Phase I and Phase II high aromatic fuels derived from a Western Kentucky coal were compared to determine the effects produced by the varying distillation range of the two fuels. The data are shown in Table II of enclosure (1). It can be seen that adjusting the distillation

range of the fuel varied all of the characteristics shown in Table II. By decreasing the initial and final boiling points, the following changes occurred:

(1) the excessive margin of the flash point value of the Phase I fuel (when compared to the JP-5 requirement) was reduced to a minimum acceptable margin for the Phase II fuel.

(2) the unsatisfactory viscosity value of the Phase I fuel was reduced to a value for the Phase II fuel that was well within the JP-5 requirement.

(3) the minimal margin in freeze point value (when compared to the JP-5 requirement) for the Phase I fuel became an excessive margin for the Phase II fuel.

(4) the specific gravity value decreased but remained above the requirement. This factor is not considered to be disqualifying from the standpoint of satisfactory gas turbine engine operation.

e. From the analysis of the data obtained, it is concluded that a JP-5 fuel that will meet all the requirements of JP-5 (reference (a)) but for specific gravity, can be derived from Western Kentucky coal.

J. Solash

J. SOLASH

R. J. DelFosse

R. J. DELFOSS

TABLE I
SPECIFICATION ANALYSIS OF HIGH AROMATIC JP-5 TYPE FUEL (PHASE I) DERIVED FROM WESTERN KENTUCKY COAL

TEST	ASTM STANDARD	JP-5 REQUIREMENTS	SUN OIL COMPANY	RESULT
Distillation Temperature, °C (°F)	D-86			
Initial Boiling Point		Report	179 (354)	171 (340)
10%		205 (401) max	184 (364)	186 (366)
20%		Report	189 (373)	189 (372)
50%		Report	199 (390)	200 (392)
90%		Report	232 (450)	234 (454)
End Point		290 (554) max	261 (502)	261 (502)
Residue, vol %		1.5 max	1.0	1.3
Loss, vol %		1.5 max	1.0	0.7
Gravity, °API	D-287	36.0 max/49.0 min	34.1	33.9
Freezing Point, °C (°F)	D-2386	-46 (-51) max	-57 (-70)	< -57 (-70)
Aromatics, vol %	D-1319	25.0 max	23.4	24.10
Smoke Point, mm	D-1322	19 min	11	18.0
Flash Point, °C (°F)	D-93	60 (140) min	60 (140)	63 (146)
Existent Gum, mg/100 ml	D-381	7 max	1.0	0.1
Sulfur, Wt. %	D-1286	0.4 max	0.00027	0.03
Thermal Stability	D-241	Pass at 260°C (500°F)	-	Fail
Heating Value, MJ/kg (BTU/lb)	D-240	42.6 (18,300) min	43.1 (18,520)	42.5 (18,281)
Viscosity, cSt @ -34°C (-30°F)	D-445	16.5 max *	8.87	9.04
Olefins, vol %	D-1319	5.0 max	1.4	0.60
Particulate Matter, mg/l	D-2276	1.0 max	5.6	14.02
Total Acid No., mg KOH/g	D-974	0.015 max	0.014	-
Nitrogen, ppm	(Modified Kjeldahl)	N/A	37	-
Carbon, Wt. %	-	N/A	87.1	-
Hydrogen, Wt. %	-	N/A	13.0	-

*Value taken from MIL-T-5624J.

ENCLOSURE (1)

TABLE II
HIGH AROMATIC FUELS DERIVED FROM WESTERN KENTUCKY COAL

	FUEL CHARACTERISTICS		JP-5 REQUIREMENTS
	PHASE I	PHASE II	
Distillation Range, °C (°F)	188-279 (371-535)	171-261 (340-502)	Report - 290 (551)
Specific Gravity	0.8751	0.8555	0.845 max*
Freeze Point, °C (°F)	-48 (-54)	< -57 (-70)	-46 (-51) max
Viscosity, $m^2/s \times 10^{-6}$ (cST) at -34°C (-30°F)	23.96	9.04	16.5 max*
Flash Point, °C (°F)	80 (176)	63 (146)	60 (140) min

*Value taken from MIL-T-5624J.

NAPTC-PE-99

OPTIONAL FORM NO.
MAY 1962 EDITION
GSA FPMR (41 CFR) 101-11.6

APPENDIX F

UNITED STATES GOVERNMENT

Memorandum

PE71:JF:sds

10340

DATE: 22 January 1977

TO : C. J. Nowack

FROM : J. Flomen

SUBJECT: NAVAIR WUA No. NAPTC-175-4R6-386 - JP-5 Type Fuel (Phase II) Derived From Coal; effect on coalescer element performance

ENCL : (1) Figures 1 through 5

1. Introduction. The chemical composition of a coal derived JP-5 type fuel differs significantly from the current petroleum derived JP-5. Because of this difference, fuel properties such as density and viscosity will be affected and possibly the water/fuel separation characteristics. These properties could very well affect the water removal efficiency of coalescers. Therefore, laboratory tests of the effects of the Phase II coal derived JP-5 type fuel (high aromatic fuel) derived from Western Kentucky coal on water coalescence were performed.

2. Conclusions.

a. The fuel derived from coal, did not have an adverse effect on the water removing ability of a typical coalescer conforming to Specifications MIL-F-52308 and MIL-F-8901.

b. Combining a small quantity of the coal derived fuel with a large amount of petroleum base JP-5 fuel altered the water removing ability of the coalescer element.

3. Recommendation. Additional tests should be performed to evaluate the effect of various coal derived fuel/petroleum base JP-5 blends on the water separation characteristics of coalescers.

4. Description of Test.

a. The Coalescer Test System consists of a 0.18 cubic meter (47 gallon) fuel tank, centrifugal pump, transparent test and clean up sections, flowmeter and connecting piping. This system is shown in figure 1 of enclosure (1).

b. Prior to filling the system with the coal derived fuel, the system was flushed and completely dried to eliminate all traces of prior fuel. New coalescer elements were installed in the test and clean up sections. The elements used were manufactured by the Velcon Corporation and were dated May 25, 1970. This particular element was selected as being a typical element conforming to Military Specifications MIL-F-52308 and MIL-F-8901.



5. Method of Test.

a. The test program was designed to condition the coalescer by passing clean dry fuel through the element for 30 minutes prior to introducing distilled water into the system. To insure complete emulsification, the water was injected into the fuel at the inlet side of the pump. The following water concentrations were added for 30 minute intervals: 0.01, 0.05, 0.1, 0.5, and 1.0 percent of fuel flow. A fuel flow of 1.3 litres per second (20 gallons per minute (gpm)) was used throughout the test sequence. The pressure differential across the element, free water in effluent fuel from the coalescer, coalesced water drop sizes, fuel and water color and drop distribution on the element surface were recorded. At the conclusion of the test, the Water Separation Index, Modified (WSIM) of the fuel was determined by using ASTM Method D-2550. This test is indicative of the water separation ability of the fuel and would indicate the presence of surface active agents (surfactants).

b. After completing the test sequence with the coal derived fuel, the system was completely drained. The system was not dried or flushed and the coalescers were not changed prior to refilling the system with the petroleum derived JP-5. By this means, a minimal concentration of coal derived fuel in petroleum derived JP-5 was achieved. The same test was then conducted on this fuel as had been conducted on the coal derived fuel.

6. Analysis of Results and Discussion.

a. Figure 2 of enclosure (1) shows the free water in the coal derived fuel effluent from the coalescer element as a function of fuel throughput and water added to the fuel. For comparison purposes, data are shown for an identical element that had been previously tested using a petroleum derived JP-5 fuel. As indicated, the coal derived fuel and regular JP-5 exhibited similar performance characteristics in the coalescer test.

b. Figure 3 of enclosure (1) shows the corresponding coalescer element pressure differential data obtained during the water tests. The trend of increasing pressure drop with increasing water concentration for both tests is similar. The reason for the high pressure differential using the coal derived fuel is the high solid contamination level of the fuel that was used. During the initial 30 minutes of operation on dry fuel, the solid contamination in the fuel was removed by the coalescer and produced the high pressure drop.

c. The water drops formed, using the coal derived fuel, were clear and large (6.35 mm (1/4 inch) in diameter) at water concentrations up to 0.1 percent. At the 0.5 and 1.0 percent water concentrations, the drop size increased to 7.94 mm (5/16 inch) diameter. Throughout the test little or no drops were formed which were smaller in diameter than noted above and the coalesced water was distributed evenly over the entire surface of the element. After the coalescer test, a WSIM test of the coal derived fuel gave a value of 99 indicating good water separation characteristics.

d. After completing the test sequence, the coal derived fuel was permitted to drain from the system for 12 hours. It was noted that the test and clean-up elements were still wet but not dripping. The system

was then filled with a petroleum based JP-5 and the testing sequence repeated. When the test housing was full and the fuel was circulating, the petroleum based JP-5 appeared to wash the coal derived fuel from the element. This phenomenon was also noted in the clean-up housing and appeared as a density gradient which disappeared after 1.1 cubic meters (300 gals) of fuel had passed through the element. Figure 4 of enclosure (1) shows the ability of the element to remove the free water added to this fuel. It is noted that the element performance has been significantly affected at the higher water concentrations of 0.5 and 1.0 percent when compared to that of the coal derived fuel test. There is no difference in performance at the lower water concentrations. The drops formed were clear and 6.35 mm (1/4 inch) in diameter up to the 0.5 and 1.0 percent water concentrations. At these higher water concentrations, smaller drops (1.59 mm (1/16 inch) and 0.79 mm (1/32 inch) diameter) were formed. These drops were carried in the coalescer effluent fuel but were removed by the Teflon screen separator. Undoubtedly smaller drops, not visible to the naked eye, were also formed which passed through the separator and resulted in the higher free water values shown in figure 4.

e. Figure 5 of enclosure (1) shows the comparison of pressure differential data across the test coalescer element at the various water concentrations for the two tests. No significant difference in the pressure differential characteristics is apparent. The WSIM value of the petroleum based fuel after the test was 99.

f. The deterioration in coalescer performance that was observed when using the petroleum derived JP-5 containing a minimal amount of coal derived fuel should be further investigated. Although the magnitude of this deterioration is not great (3 ppm), this condition could become serious with fuel blends containing different ratios of these fuels if the condition noted is a real effect and not the results of some testing inconsistency.

J. Flomen
J. FLOMEN

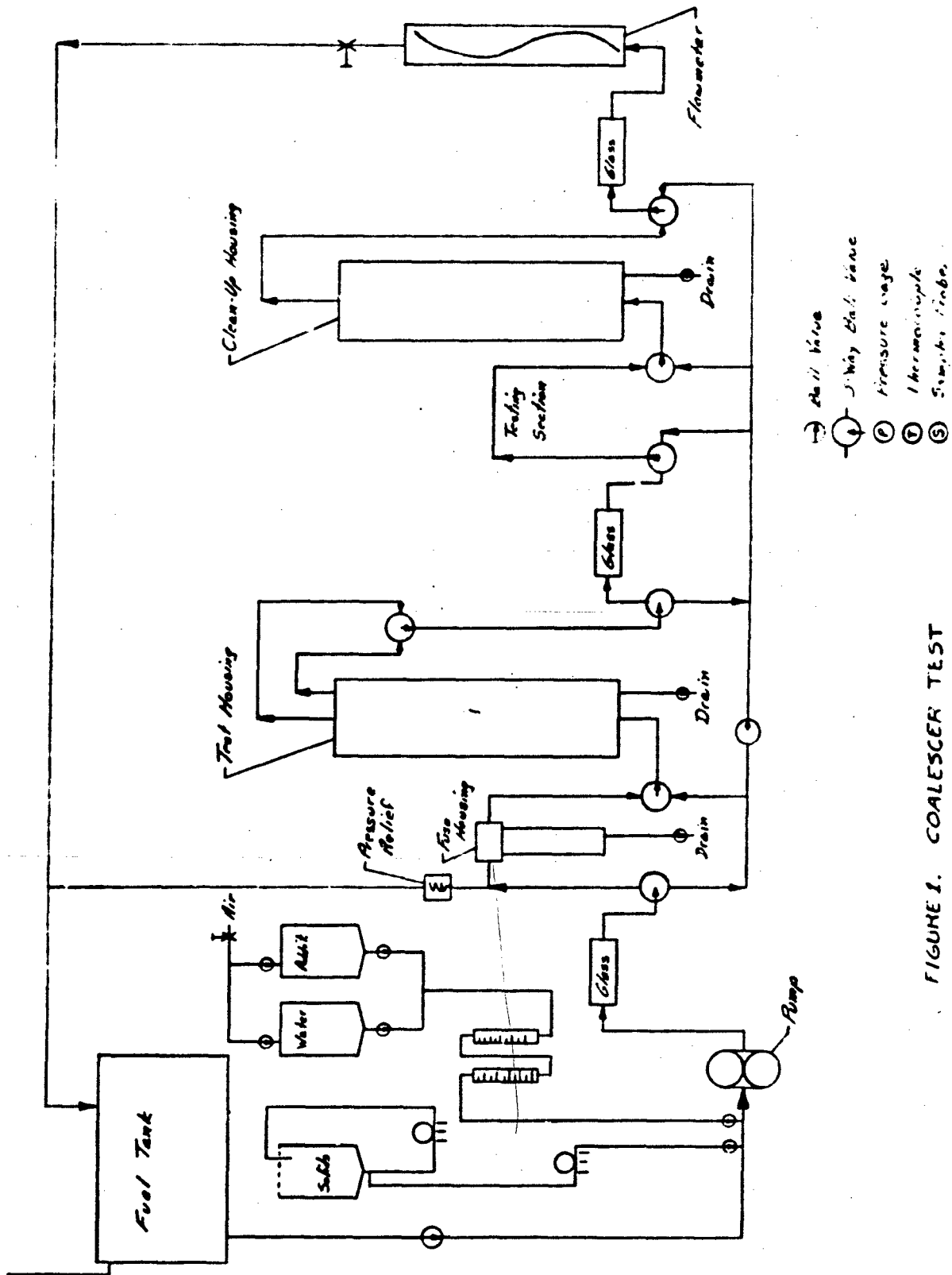
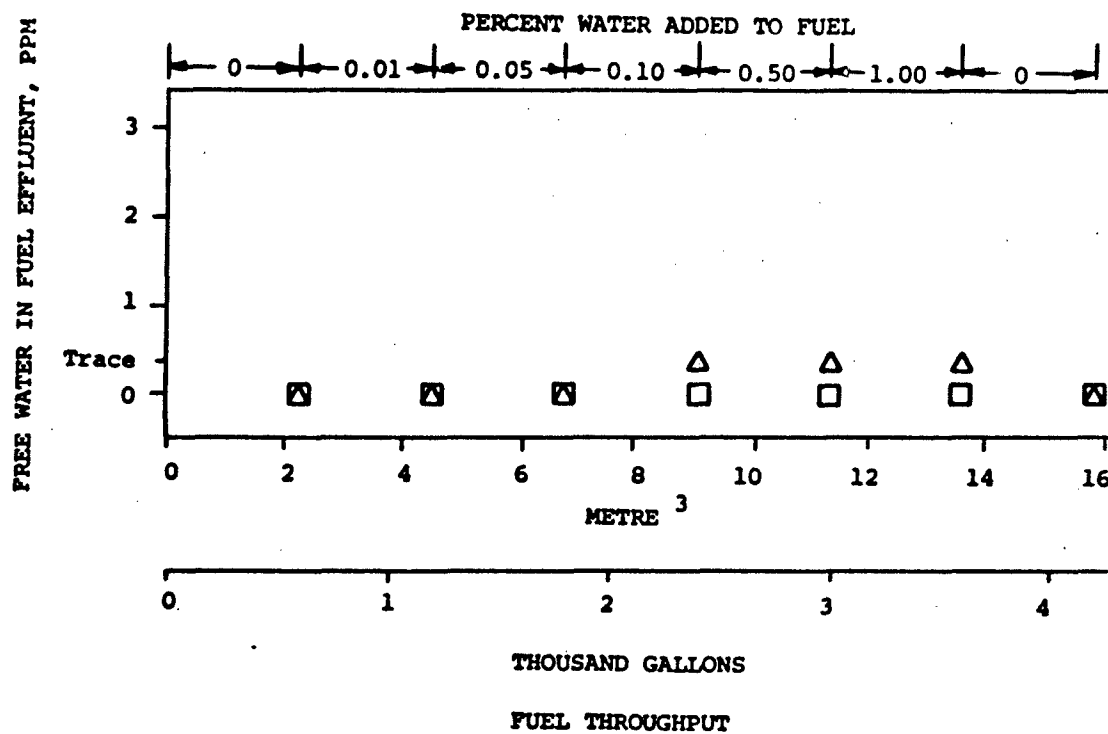


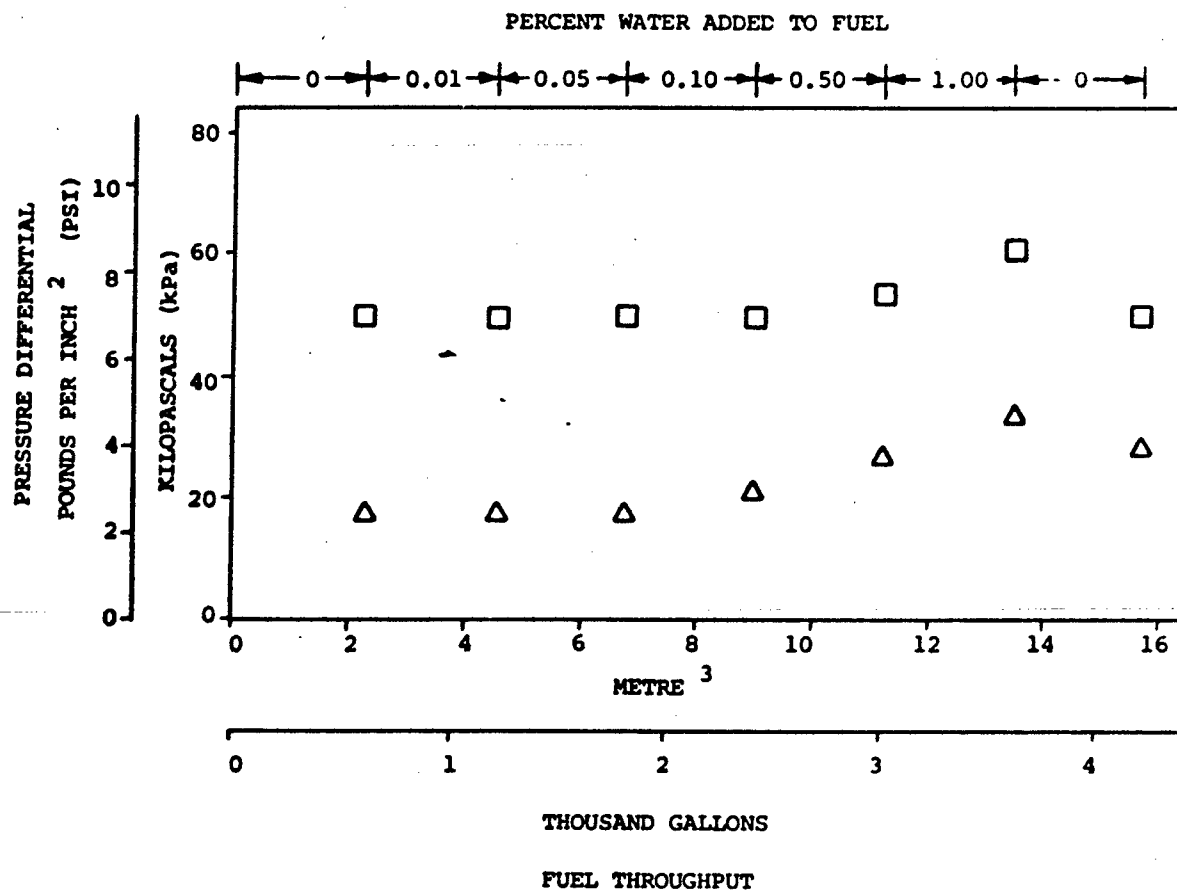
FIGURE 1. COALESCE TEST

FIGURE 2. WATER REMOVING ABILITY AT VARIOUS WATER CONCENTRATIONS



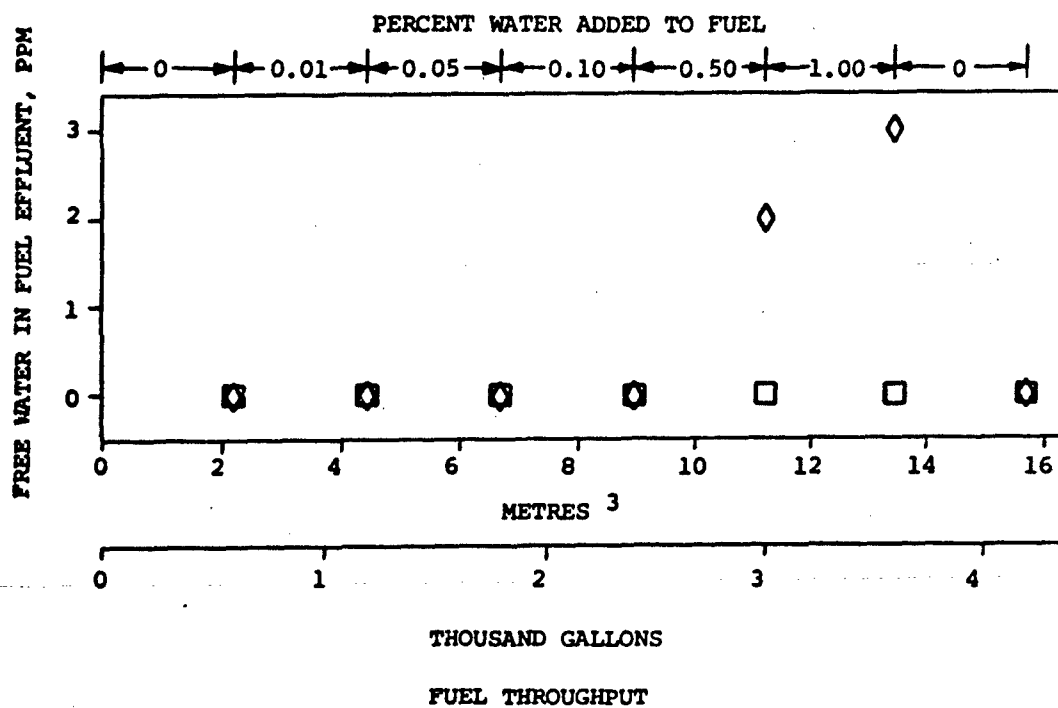
- COAL DERIVED FUEL
- △ PETROLEUM BASE JP-5

FIGURE 3. PRESSURE DIFFERENTIAL AT VARIOUS WATER CONCENTRATIONS



- COAL DERIVED FUEL
- △ PETROLEUM BASE JP-5

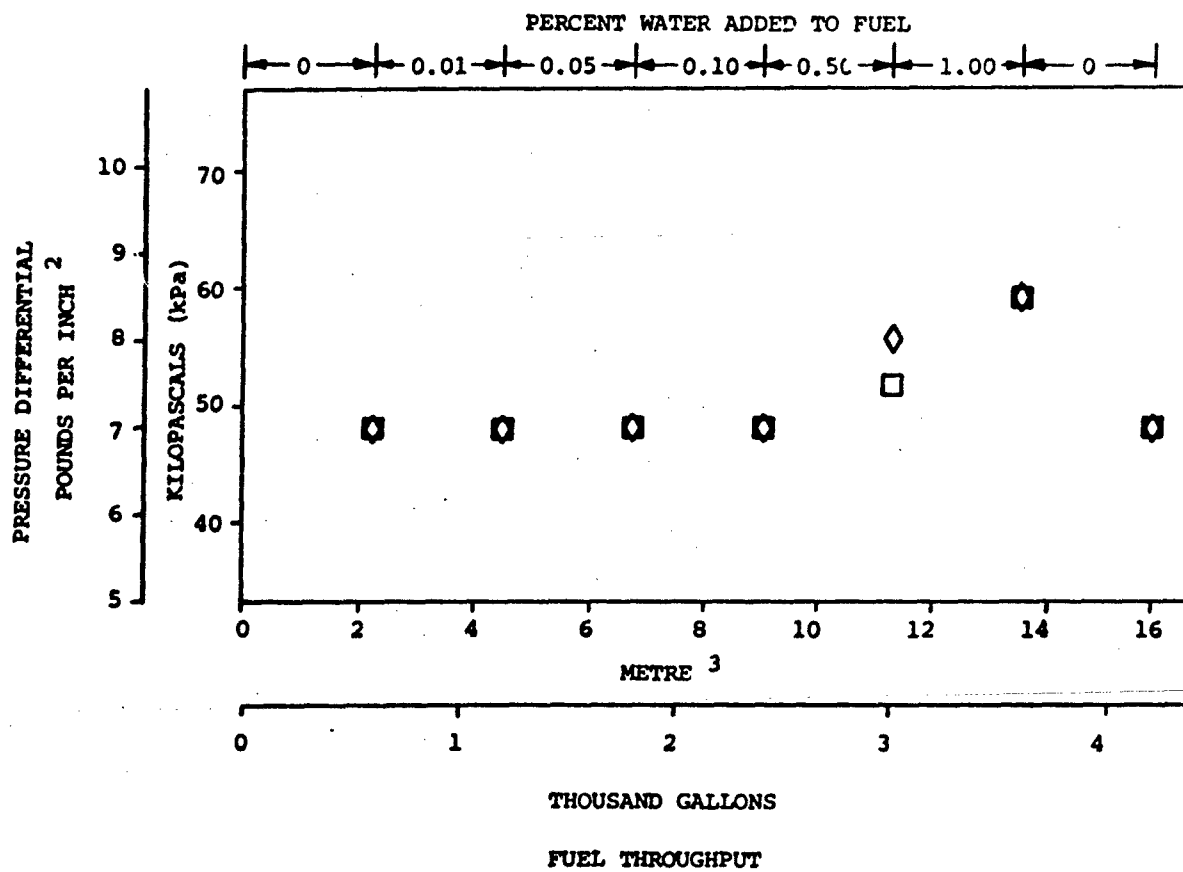
FIGURE 4. WATER REMOVING ABILITY AT VARIOUS WATER CONCENTRATIONS



□ COAL DERIVED FUEL

◇ PETROLEUM BASE JP-5 CONTAINING SMALL AMOUNT OF COAL DERIVED FUEL

FIGURE 5. PRESSURE DIFFERENTIAL AT VARIOUS WATER CONCENTRATIONS



UNITED STATES GOVERNMENT

Memorandum

PE71:JS:GES:sds

10340

DATE: 23 January 1977

TO : C. J. Nowack

FROM : J. Shimski, G. E. Speck

SUBJECT: NAVAIR WUA No. NAPTC-175-4R6-386 - JP-5 Type Fuel (Phase II) Derived From Coal; T63-A-5A engine performance/exhaust emission testing of

- REF : (a) Sun Oil Company Contract No. N00140-74-C-0568, Mod. P00001; Preparation of Gas Turbine Fuel from Synthetic Crude Oil Derived from Coal; final report
(b) Allison Model Specification No. 580-J dated 30 Sept 1970
(c) Society of Automotive Engineers Aerospace Recommended Practice, ARP-1256
(d) Federal Register, Volume 38, Number 136, 17 July 1973, Emission Standards and Test Procedures for Control of Air Pollution from Aircraft and Aircraft Engines

- ENCL : (1) Tables I and II
(2) Figures 1 through 4, inclusive

1. Introduction. A JP-5 type fuel derived from coal was provided by contract, reference (a), in sufficient quantity to conduct short T63-A-5A engine performance and exhaust emission tests under sea level environmental conditions. This report covers the details of these tests.

2. Conclusions.

a. The JP-5 type fuel derived from coal performed satisfactorily in a T63-A-5A engine under sea level environmental conditions.

b. The carbon monoxide (C), total unburned hydrocarbons (THC) and oxides of nitrogen (NO_x) emissions for the coal derived JP-5 type fuel were equivalent to those obtained with the petroleum derived JP-5 in the T63-A-5A engine.

3. Recommendation. Continue testing of fuels derived from coal in current aircraft engines under more stringent conditions of time, temperature and altitude, to establish engine performance and endurance.

4. Description.

a. The Allison T63-A-5A engine is a turboshaft engine of the free turbine type and is used in the Army OH-58A and Navy TH-57A helicopters. The gas producer section is composed of a combination six-stage axial flow-one stage centrifugal flow compressor directly coupled to a two-stage free turbine which is gas coupled to the gas producer turbine. The engine contains an integral reduction gearbox (5.84:1) which provides an internal



spline output drive at the front of the gearbox. The engine has a single combustion chamber. The output shaft centerline is located below the centerline of the engine rotor and the exhaust is directed upward through dual exhaust pipes. An air bleed valve at the fifth compressor stage is provided to insure surge free accelerations. The power turbine inlet temperature indication (T5) is provided by the average of four thermocouples located in the power turbine nozzle. The performance ratings of the T63-A-5A engine as specified in reference (b) are shown in Table I of enclosure (1). The engine (Serial Number W-33) was supplied by NAPTC. Prior to this test, it had logged an undetermined number of hours since new and two hours since overhaul.

b. The coal derived JP-5 type fuel tested is a hydrotreated kerosene that had been fractionated from a Western Kentucky syncrude (Sample 0005).

5. Method of Test.

a. **Engine Performance.** The T63-A-5A engine (Serial No. W-33) was installed in a sea level test cell using a three-point mounting system. A flywheel and an Industrial Engineering Water Brake, type 400 were connected to the engine gearbox assembly at the forward power output pad to absorb the engine power. The brake reaction was measured by a Baldwin load cell. All parameters to determine the engine starting and steady-state performance with the fuels were measured using standard test cell instrumentation. The engine was cleaned with a twenty percent solution (by volume) of B&B 3100 and distilled water prior to performing this test program.

b. The following cycle, which is a modification of Specification MIL-E-8595 qualification cycle, was used for the engine/fuel performance tests. The cycle had been modified for a lube evaluation study that was being run concurrently with these tests.

PERFORMANCE TEST CYCLE

<u>Engine Power Rating</u>	<u>Time (minutes)</u>
Cold Start	
Ground Idle	2
Normal Rated	10
Ground Idle	2
Maximum	5
Normal Rated	55
Maximum	5
Ground Idle	1
Chop	
<hr/>	
TOTAL TIME	80

Engine inlet air and fuel temperatures during the program were between 27°C (80°F) and 32°C (90°F).

c. Exhaust Emissions. The exhaust emission samples for JP-5 and the coal derived fuel were taken at the following engine conditions, in sequence, for the pollutants measured.

EMISSION TEST CYCLE

<u>Engine Power Rating</u>	<u>Time (minutes)</u>
Cold Start	-
Maximum	10
Normal Rated	10
90% Normal Rated	10
60% Normal Rated	10
40% Normal Rated	10
Flight Idle	10
Ground Idle	10
<hr/>	
TOTAL TIME	70

d. This cycle was then repeated to provide duplicate data. Throughout the test program the power turbine (NPT) was kept at a constant speed of 100 rps (6,000 rpm) except at ground idle. The engine power ratings designated for the emission survey were selected as being representative of a typical Army helicopter duty cycle. No engine bleed airflow was extracted from the engine during emission sampling except at ground idle and flight idle, when the compressor fifth stage acceleration bleed valve is automatically open. The compressor fifth stage acceleration bleed airflow is defined by the manufacturer in figure 60 of reference (b). The fuel-air ratio was calculated for each power rating with compensation made for the fifth stage bleed leakage at ground idle.

e. The instrumentation and methods of analysis for the engine emissions were in accordance with references (c) and (d).

f. The calibration gases used with the test instruments were purchased from Scott Research Laboratories and Matheson Gas Products. The specific gases used were:

- (1) CO - 1200 ppm, 890 ppm, 441 ppm, 250 ppm, 75 ppm, 25 ppm
- (2) CO₂ - 4.74%, 3.0%, 2.0% 1.0%
- (3) NO + NO₂ - 190 ppm, 83.9 ppm + 6 ppm, 28.1 + 2.6 ppm
- (4) THC - 459 ppm, 408 ppm, 357 ppm, 200.4 ppm, 146.4 ppm, 36.6 ppm

The accuracy of all the above gases was guaranteed by the vendors to be +1 percent. The concentrations of these gases were controlled by availability and NAPTC needs, and do not exactly match the requirements in reference (c).

g. Emission sampling was done with a probe fabricated in accordance with references (c) and (d). Two probes were made because of the dual

tailpipe configuration. They were made of stainless steel with four arms extending from a central manifold. The plane of each probe was an ellipse with major and minor axes of 232 mm (9 1/8 in) and 178 mm (7 in). There were three 1.5 mm (0.060 in) diameter holes at the centers of equal areas on each arm. The probes were centered in the exhaust stream 41 mm (1 5/8 in) downstream of the exhaust pipe exit. A probe was mounted in each exhaust pipe.

h. The emissions sampling line was stainless steel with an internal diameter of 7.7 mm (0.305 in). It was maintained at a temperature of 150°C \pm 5°C (302°F \pm 9°F). Nitrogen was blown back through the probe during engine start-up to preclude the deposition of raw fuel in the sampling lines.

6. Analysis of Results.

a. Characteristics of Test Fuels - The fuel derived from coal and the JP-5 used in the T63-A-5A engine performance and emissions tests were analyzed to determine their characteristics. These data are shown in Table II of enclosure (1) along with the average data for JP-5 fuels produced during 1975 and the JP-5 specification limits. The coal derived fuel was deficient in gravity, heat of combustion, smoke point, contamination and thermal stability when compared to the JP-5 specification limits. None of these deficiencies were of sufficient magnitude to cause concern about the use of this fuel in an engine in a test cell. The excessive amount of solid contamination present in the fuel was removed by filtration in the test cell fuel system. The JP-5 used to obtain comparison or base line data conformed to the specification requirements.

b. T63-A-5A Engine Performance - The performance obtained on the fuel derived from coal and the JP-5 fuel are shown in figure 1 of enclosure (2). The guarantee model specification values (reference (b)) are also shown for comparison purposes. It can be seen that there is no significant difference in the T63-A-5A engine performance with these fuels and that the engine performance conforms to the model specification requirements.

c. T63-A-5A Engine Exhaust Emission - The values for CO, THC and NO_x for the fuel derived from coal and JP-5 are presented in figures 2, 3 and 4 of enclosure (2). They are plotted as a function of engine fuel-air ratio. No significant difference in exhaust emission characteristics is apparent when comparing the fuel derived from coal data with that of the JP-5 fuel.

John Shimski
J. SHIMSKI

G. E. Speck
G. E. SPECK

TABLE I
PERFORMANCE RATINGS - STANDARD SEA LEVEL STATIC CONDITIONS

Ratings	Shaft Power* watts (HP)	Net Jet Thrust* Newton (lb-force)	Gas Producer Shaft Speed, est. rpm (rpm)	Output Shaft Speed rpm (rpm)	Specific Fuel Consumption** g/kwh	RAM Power Rating Torque at Output Shaft** N·m (ft-lb-force)	Measured Rated Gas Temperature, °C (°F)
Takeoff and Military	236 x 10 ³ (317)	147 (33)	860 (51600)	100 (6000)	1.177 x 10 ⁻⁷ (0.697)	397 (293)	749 (1380)
Normal	201 x 10 ³ (270)	125 (28)	829 (49760)	100 (6000)	1.193 x 10 ⁻⁷ (0.706)	338 (249)	693 (1280)
90% Normal	181 x 10 ³ (243)	116 (26)	811 (48630)	100 (6000)	1.225 x 10 ⁻⁷ (0.725)	338 (249)	663 (1226)
75% Normal	151 x 10 ³ (203)	93 (21)	782 (46950)	100 (6000)	1.288 x 10 ⁻⁷ (0.762)	338 (249)	638 (1145)
Ground Start and Ground Idle	26 x 10 ³ (35) max	44 (10) max	533 (32000)	75-105 (4500-6300)	7.69 x 10 ⁻³ kg/s 61 (lb-weight/hr)	-	385 ± 56 (725 ± 100)
Flight Auto- rotation	0 (0) max	44 (10) max	533 (32000)	98-106 (5900-6360)	7.68 x 10 ⁻³ kg/s 61 (lb-weight/hr)	-	385 ± 56 (725 ± 100)

* Minimum Value.

** Maximum Value.

*** kg/W.s (lb-weight/SHP-hr).

TABLE II
PROPERTIES OF JP-5 AND JP-5 TYPE FUEL DERIVED FROM COAL

	Coal Derived Fuel	T63 Calibration JP-5	Average JP-5 Characteristics*	MIL-T-5624K REQUIREMENTS	
				Minimum	Maximum
Gravity, Specific, 16/16°C (60/60°F)	0.855**	0.8114	0.8170	0.788***	0.845***
Gravity, API, 16/16°C (60/60°F)	31.9**	42.9	41.5	36.0	48.0
Distillation, I.B.P., °C (°F)					
5% Recovered °F	471 (340)	177 (350)	184 (363)	-	-
10% Recovered °F	183 (342)	188 (370)	-	-	-
20% Recovered °F	186 (346)	192 (378)	198 (388)	-	205 (401)
30% Recovered °F	189 (372)	198 (388)	203 (397)	-	-
40% Recovered °F	192 (378)	202 (396)	-	-	-
50% Recovered °F	196 (364)	208 (406)	-	-	-
60% Recovered °F	200 (392)	213 (416)	216 (418)	-	-
70% Recovered °F	204 (400)	217 (423)	-	-	-
80% Recovered °F	210 (410)	223 (434)	-	-	-
90% Recovered °F	219 (426)	229 (444)	-	-	-
95% Recovered °F	234 (454)	238 (460)	239 (462)	-	-
95% Recovered °F	279 (481)	246 (474)	-	-	-
End Point, °C (°F)	51 (502)	258 (496)	257 (495)	-	294 (554)
Recovery, vol %	98	98.5	-	-	-
Residue, vol %	1.3	1.0	1.1	-	-
Loss, vol %	0.7	0.5	0.9	-	1.5
Sulfur, wt %	0.1	0	1.0	-	7
F.I.A. Saturates, vol %	0.03	0.06	0.061	-	0.4
Olefins, vol %	75.3	80.86	-	-	-
Aromatics, vol %	0.6	0.95	1.2	-	5.0
Aniline Point, °C (°F)	24.10	19.19	15.2	-	25.0
Aniline Gravity Constant	40 (104)	61.7 (143.1)	-	-	-
Heat of Combustion, MJ/kg (BTU/lb)	3,526	6,139	5,840	4,500	-
Corrosion, Copper Strip	42.5 (18,283)	43.2 (18,560)	43.1 (18,522)	42.6 (18,300)	-
Smoke Point, mm	1-A	1-A	-	-	1-B
Freeze Point, °C (°F)	18**	28	22.9	19	-
Flash Point, °C (°F)	6-57 (-70)	-50 (-58)	-40 (-56)	-	-46 (-51)
Viscosity, CST, -34°C (-30°F)	63 (146)	63 (146)	-	60 (140)	-
Contamination, mg/liter	9.04	9.40	9.0	-	16.5***
Thermal Stability @ 260°C (500°F)-(-L. POP)	14.02**	1.80	-	-	1.0
Water Separator Test, Modified	Fail**	Pass	Pass	Pass	Pass
	99	98	94	95	-

* ERMA Report BRC/PPS-76/2 - Aviation Turbine Fuels, 1975.

** Value does not meet JP-5 requirement.

*** Value taken from MIL-T-5624J.

FIGURE 1. PERFORMANCE OF A T63-A-5A ENGINE WITH JP-5 DERIVED FROM COAL

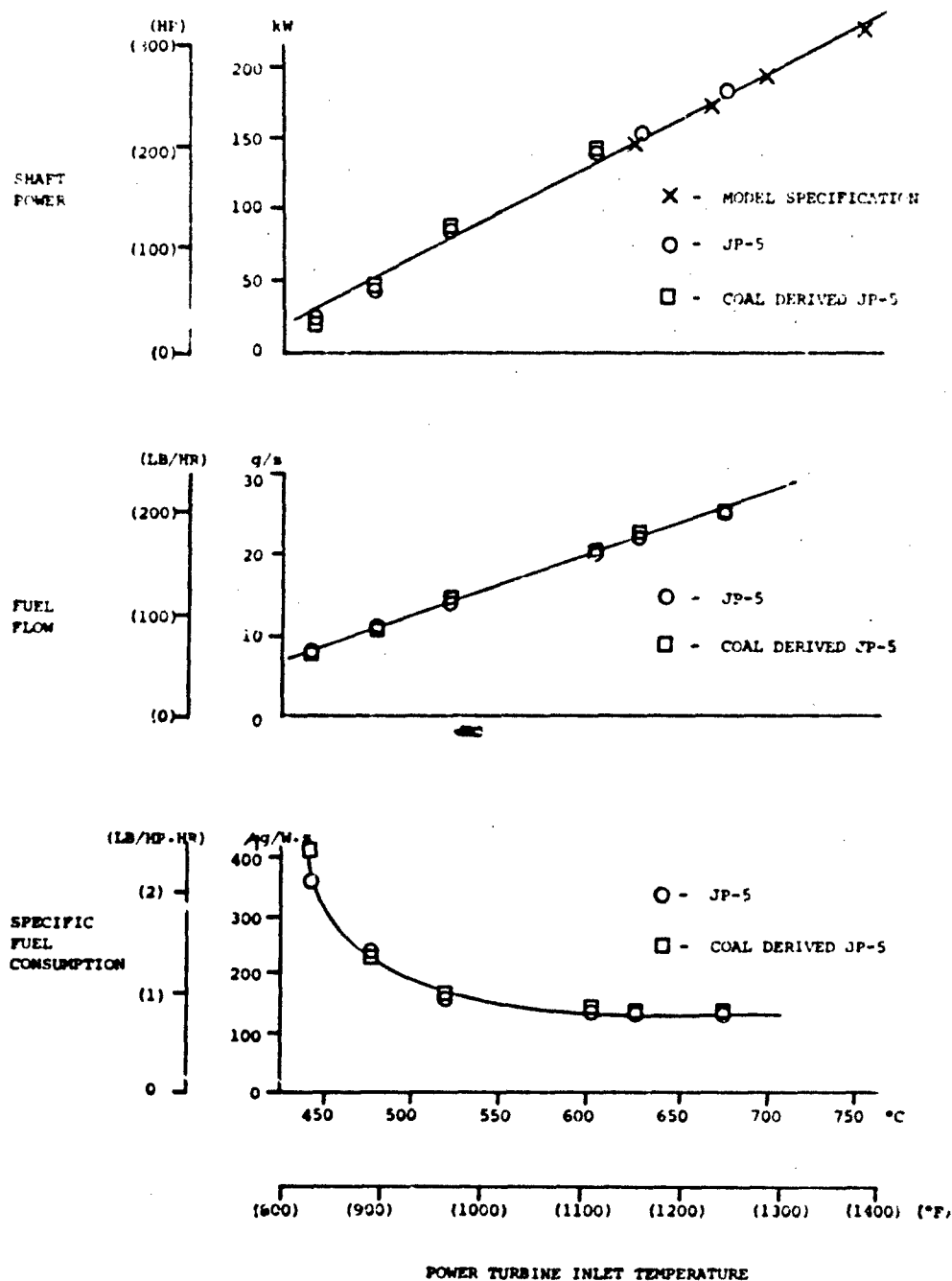
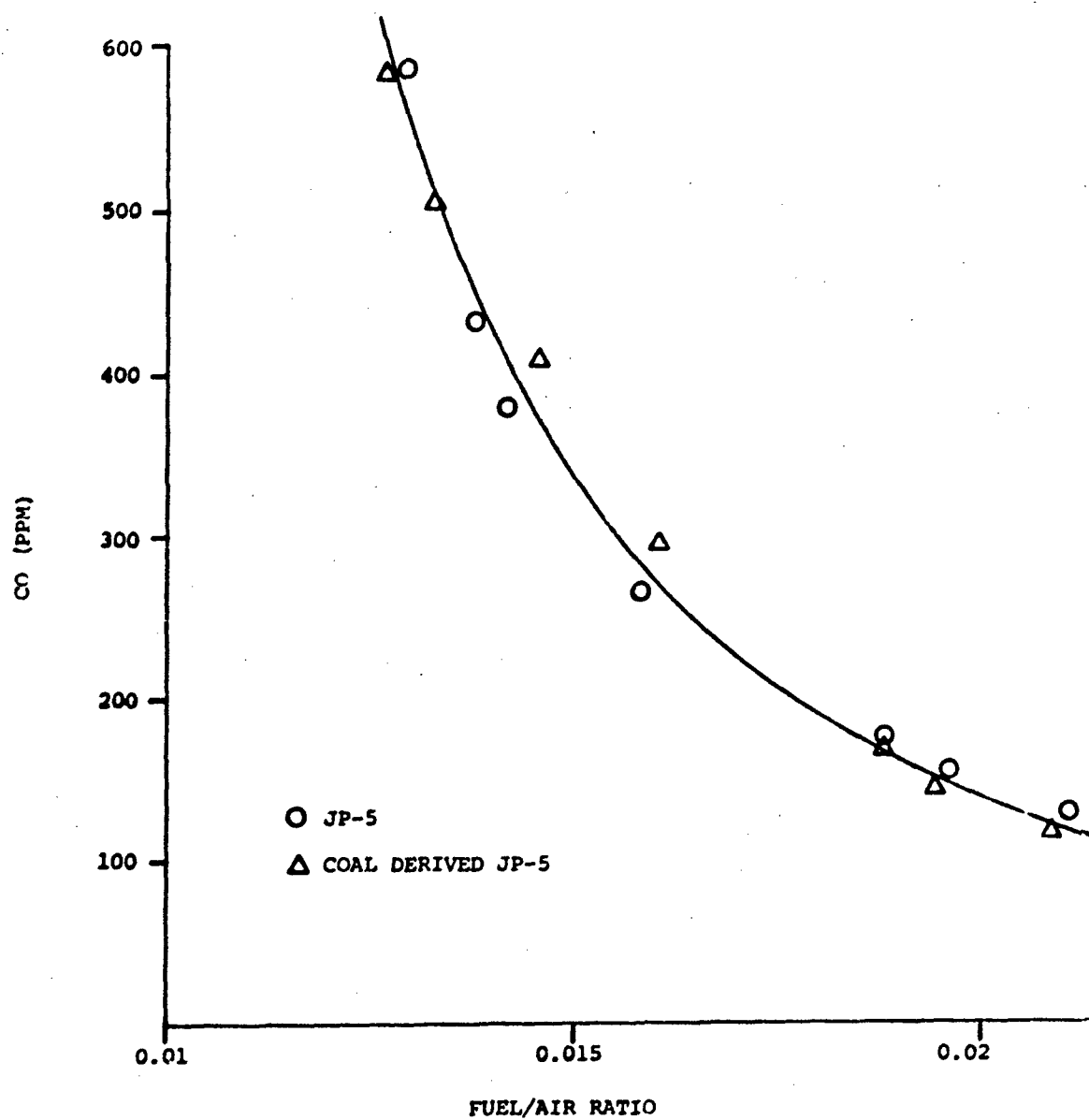


FIGURE 2. CARBON MONOXIDE EMISSIONS, T63-A-5A ENGINE, S/N W-33



NAPTC-PE-99

FIGURE 3. TOTAL UNBURNED HYDROCARBON EMISSIONS, T63-A-5A ENGINE,
S/N W-33

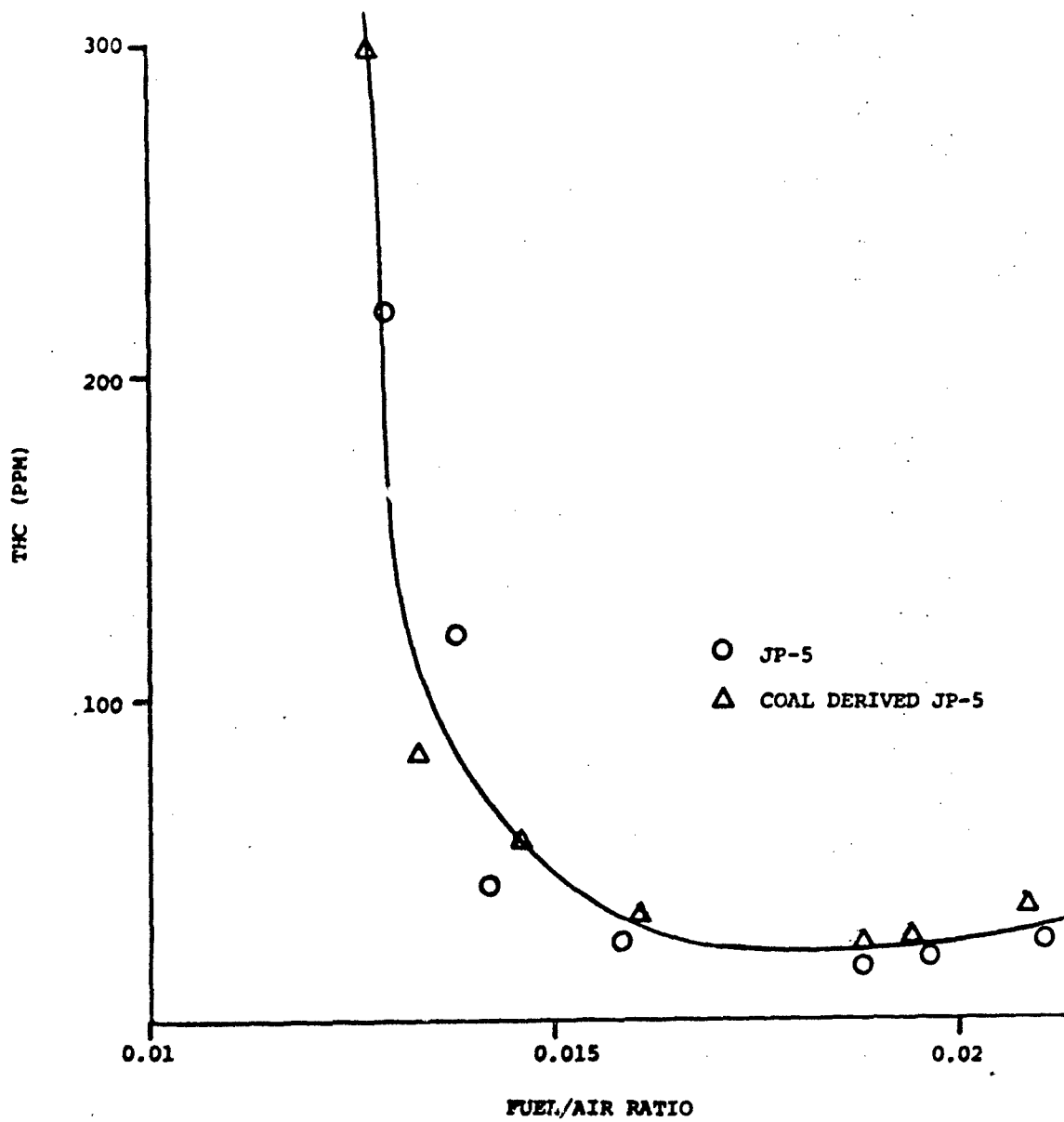
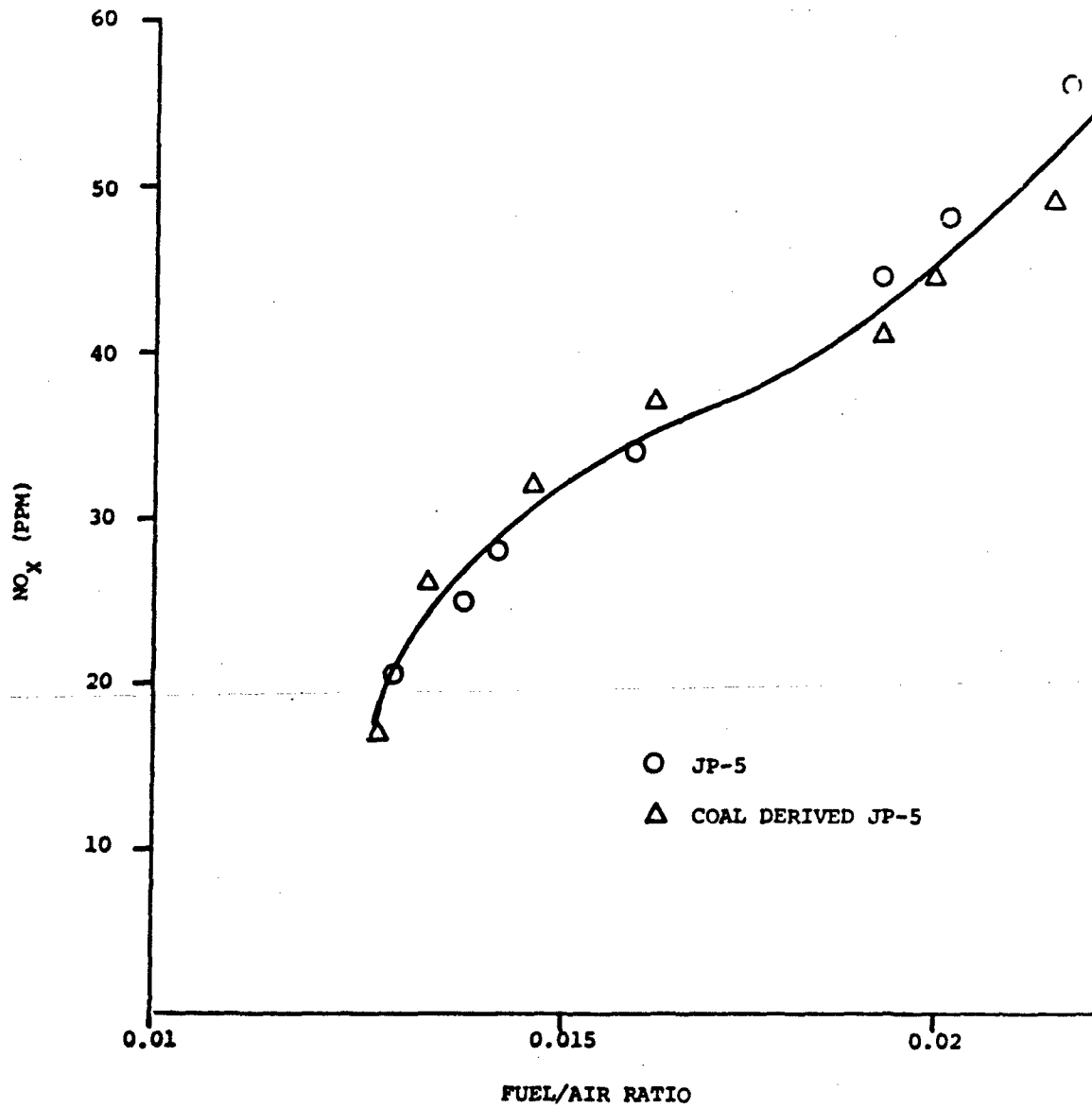


FIGURE 4. NITROGEN OXIDE EMISSIONS, T63-A-5A ENGINE, S/N W-33



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